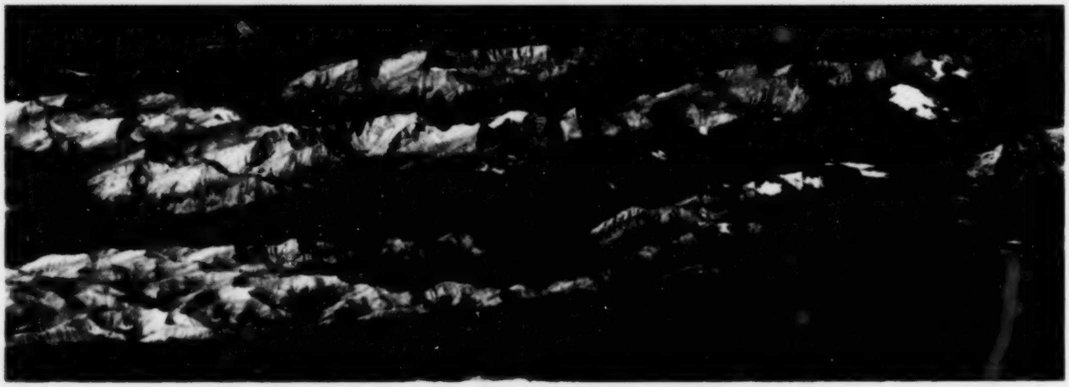
Hydrogeology of the Canmore Corridor and Northwestern Kananaskis Country, Alberta



Western Economic
Diversification Canada

Canada

Alberta
ENVIRONMENT

Hydrogeology of the Canmore Corridor and Northwestern Kananaskis Country, Alberta

Western Economic Diversification Canada
Canada
Alberta
ENVIRONMENT

© Her Majesty the Queen in Right of Alberta, 2002

ISBN 0-7785-2294-6 (print version)
ISBN 0-7785-2295-4 (electronic version)

Alberta Environment, its employees and contractors make no warranty, guarantee or representation, express or implied, or assume any legal liability regarding the correctness, accuracy, completeness, or reliability of this publication. Any digital data and software supplied with this publication are subject to the licence conditions (specified in "Licence Agreement for Digital Products"). The data are supplied on the understanding that they are for the sole use of the licensee, and will not be redistributed in any form, in whole or in part, to third parties. Any references to proprietary software in the documentation and/or any use of proprietary data formats in this release does not constitute endorsement by Alberta Environment of any manufacturer's product, nor does the use of any particular contractor or service.

When using information from this publication in other publications or presentations, due acknowledgment should be given to Alberta Environment. The following reference format is recommended:

> Toop, D.C. and N. N. de la Cruz, 2002. *Hydrogeology of the Canmore Corridor and Northwestern Kananaskis Country, Alberta;* Alberta Environment, Hydrogeology Section, Edmonton, Alberta; Report to Western Economic Partnership Agreement, Western Economic Diversification Canada.

Published by:
Alberta Environment
Hydrogeology Section
10th Floor, Oxbridge Place
9820 – 106 Street
Edmonton, Alberta
T5K 2J6

Telephone: (780) 427-5883
Fax: (780) 422-4192

Website: www3.gov.ab.ca/env/info/infocentre/publist.cfm

The project team acknowledges the significant funding to this project by the Federal Ministry of Western Economic Diversification through the Western Economic Partnership Agreement with the Province of Alberta.

Executive Summary

The Canmore Corridor—that portion of the Bow Valley between Banff National Park and the Stoney Indian Reserve—has experienced exceptional population growth in the last 20 years and is expected to maintain its robust growth in the foreseeable future. The adjoining northwestern portion of Kananaskis Country—comprising the Kananaskis and Spray Lakes valleys—provides attendant recreational opportunites, which are also growing in popularity. These development pressures are increasing the regional need for adequate supplies of quality drinking water, drawn primarily from groundwater aquifers and springs. Moreover, such pressures have the potential to impact water supplies further downstream, as the Bow and South Saskatchewan river systems depend on the mountain watersheds for their water supply.

This study was conducted to collect baseline data to provide an assessment of the groundwater capabilities of the Canmore Corridor and northwestern Kananaskis Country, including groundwater availability, quality, movement and interaction with the natural environment. The study was initiated in 1999 by the Hydrogeology Section of Alberta Environment under the auspices of the Western Economic Partnership Agreement (WEPA), which is a partnership between Western Economic Diversification Canada and Alberta Environment in support of groundwater research in Alberta.

Existing groundwater data were gathered from Alberta Environment's Groundwater Information Centre (GIC) database, and deficiencies were identified, both in the extent and completeness of records and in their format. The existing records were then field-verified and improved, a pertinent database and mapping protocol was devised, the area was surveyed by air in late winter to detect additional discharge areas, and a supplementary drilling program was completed to shed light on groundwater flow and quality in the region and to develop a model for Canmore.

Between June 1999 and October 2001, the sites of 670 groundwater data locations—such as wells, test holes and springs—were confirmed, and their positions and elevations to within ten centimetres were determined with a customized Ashtec geographic postition system (GPS). Twenty-one investigative test holes were drilled: two in Canmore, two in Exshaw, one near Lac des Arcs, one in Harvie Heights, one in Dead Man's Flats, seven in the region surrounding Seebe, and seven in the Spray Lakes Valley; 13 of those holes were further completed as wells. The area was surveyed by air from March 15 to 17, 2000, to identify major springs in areas with limited access. At 160 of the 670 survey sites, water samples were collected for detailed water quality analyses of major ions and trace metals. One hundred and thirty samples—mainly from wells and springs, but also from snow, rain and surface water—were also collected to examine the ratios of oxygen and hydrogen isotopes that might reveal the water's origin and interaction with its environment.

To store, manage and present the existing and new data, a Microsoft Access database was developed, from which 24 maps and 10 cross sections were produced of bedrock topography, drift thickness, aquifer distribution, groundwater flow, aquifer yield and groundwater chemistry. Using *Modflow*, a three-dimensional model was then constructed of groundwater flow of the unconsolidated valley aquifer for the area surrounding the Town of Canmore so that the effects of environmental impacts on the groundwater system could be simulated.

The investigations found four aquifer types of surficial deposits in the region: the Benchlands Aquifers, Outwash Plain Aquifer, Alluvial Fan and Valley Aquifers, and Calgary Buried Valley Aquifer. Bedrock—a fifth aquifer type of limited yield—underlies surficial deposits.

The Benchlands Aquifers flank the western end of the Bow Valley near Canmore beneath Harvie Heights, the Alpine Resort Haven at Dead Man's Flats, and the Canmore subdivisions of Silver Tip and Three Sisters. They comprise the coarse, permeable south-facing benchlands, which have low water tables, and the north-facing benchlands, which are less permeable and are thin with poor yields. The unconfined Outwash Plain Aquifer provides variable yields to the Bow Valley Provincial Park / Seebe district and sustains several pothole lakes, such as Middle Lake and Chilver Lake. Alluvial Fan and Valley Aquifers are found in the Bow, Kananaskis and Spray Lakes valleys and are especially reliable in the first two.

A significant finding from the deep investigative drilling was the western extension of the Calgary Buried Valley Aquifer, which was previously known to traverse southern Alberta from the Saskatchewan border west to Calgary. Drilling indicates that this aquifer continues up the Bow Valley—through Exshaw and Canmore—toward Banff.

Bedrock aquifers are seldom used in the region because producing wells can usually be obtained from surficial deposits. Areas that lack sufficient drift aquifers are either inaccessible mountainsides or areas with surface water supplies. Yields and water quality from wells in bedrock aquifers tend to be poor.

Most groundwater samples from aquifers exhibit a similar chemistry to that of the Bow River, which is calcium-magnesium-bicarbonate-sulphate type. The relative proportions of magnesium, calcium and bicarbonate vary in a small range throughout the region.

Water quality for the region is good. With few exceptions, the major cations and anions are within the maximum allowable concentrations (MAC) and aesthetic objectives (AO) of The *Guidelines for Canadian Drinking Water Quality (2001)* for all of our 333 samples. A few samples exceeded the AO of 500 mg/L for total dissolved solids, but these were mostly springs and a scattering of wells in the Dead Man's Flats area. However, the AO of 500 mg/L is rarely met in most of rural Alberta well water supplies, where 1000 mg/L is commonly considered acceptable.

Iron concentrations exceeding the AO were not uncommon, but were fairly isolated and were specific to individual wells. High iron was typically associated with sporadically used wells with iron casing or where iron-reducing bacteria were present.

Fluoride and nitrate were within the MAC, as were mercury and arsenic, which were mostly undetectable. Lead was within the MAC and near the detection limits for nearly all samples. Trace metals generally appeared in minute amounts, if at all.

Anthropogenic deterioration of groundwater is evident in a few cases. For example, elevated sodium and chloride, seen in Harvie Heights, Exshaw, Bow Valley Provincial Park and the Kananaskis Valley, are likely from septic fields or road salt. Similarly, at Willow Rock Spring, in Bow Valley Provincial Park, elevated levels of sodium, chloride and nitrate have appeared in the twenty years since the campground facilities were constructed.

Seventy-five springs were documented—40 in the Bow Valley, 26 in the Kananaskis Valley and 9 in the Spray Lakes Valley—a sizeable increase from the 27 that were originally listed in the GIC database. Of the 48 additions, 21 were identified by aerial survey only; an additional 27 were verified during ground reconnaissance.

The types of springs vary, and the reasons for their occurrence may not always be obvious or may be a combination of factors. Five types of springs were delineated: topographic, contact, stratigraphic, thrust-fault and karst. Flow rates varied from slow seepages to more than 9000 L/min, the latter occurring at Many Springs in Bow Valley Provincial Park.

Mineral deposition associated with springs is fairly minor in most of the Bow Valley-Kananaskis region, although spring water is usually more mineralized than surface water. Deposition usually consists of fine precipitates of calcium carbonate in streambeds or as coatings on rocks near the discharge point. Although iron deposition from springs is common in Alberta, it appears to be rare in the mountains, and few springs in our study area had noticeable precipitation.

Significant springs of the Bow Valley include Many Springs, the Bow Valley Provincial Park Lake Complex, Yamnuska Marl Spring, Railside Spring, the Bow Flats, Grassi Lakes, Canmore Sulphur Spring and the Fern Forest of Harvie Heights. Spray Lakes Valley is home to Spurling Spring and the Watridge Karst Spring, while Kananaskis Valley has the POW Spring and Evan-Thomas Spring as notable discharges.

Springs have played an important role in the cultural development of the region since the discovery of the Banff Hot Springs in 1883. Today, they are appreciated as unique natural entities with a variety of special characteristics, such as the "boiling" sediment at Many Springs, the Great Fen of Yamnuska Marl Spring, the azure blue lakes and green algae carpet of Grassi Lakes, the sulphur pool at Canmore Sulphur Spring, the Fern Forest of horsetail in Harvie Heights, the luxurious growth of moss at Spurling Spring and the old-growth spruce forest near the Watridge Karst Spring.

Springs are often special ecological sites. Their relatively warm and constant temperatures, the surrounding high humidity and their discharging of minerals makes an ideal environment for lush vegetation growth, which sometimes includes rare plants, such as round-leaved orchids, yellow lady's slippers, elephant head and insect-eating butterworts. They also provide habitat for unique animals, such as sightless aquatic isopods, and for salamanders, which need isolated, predator-free lakes, such as Chilver Lake. The warm and clear waters of Bill Griffiths Creek and nearby stream channels constitute the most important trout spawning area on the Bow River, which itself is often too cool and turbid from surface runoff. And, Lac des Arcs and Gap Lake, fed by high-volume, relatively warm springs, are important waterfowl staging areas in spring and fall.

The Bow Valley-Kananaskis region hosts three natural subregions or ecoregions: Montane, Subalpine and Alpine. The Montane benefits substantially from redistribution of water from the more elevated ecoregions. Being primarily a discharge zone, it garners a positive soil moisture balance and a notable increase in water availability, expressed in the alluvial fans, springs, streams and lakes. And, because the groundwater flow typically has a long residence time, an enhanced concentration of dissolved matter brings nutrients with the flow. These moist, nutrient-rich discharge areas contrast with the dry, nutrient-poor recharge areas that remain in other parts of the Montane, augmented by the warmer climate, to create a high degree of biodiversity.

To a lesser extent, the Subalpine ecoregion benefits from groundwater redistribution, especially in the Spray Lakes and upper Kananaskis valleys, where it occupies the discharge areas. However, the Subalpine does not have the warmer, drier climate of the Montane and the groundwater flow distance is not usually as great, so its benefits are not as prominent and are often more localized.

The Alpine ecoregion, while receiving the most precipitation, is a net loser from groundwater redistribution as most of its groundwater flows to lower elevations. However, in flow-through and discharge areas, such as alpine meadows, diverse and productive plant assemblages provide critical feeding and nesting habitat for a variety of animal species.

As an essential component of the hydrologic cycle, groundwater helps create and maintain the biodiversity of the ecoregions: it modifies the extremes of climate and imprints a variety of moisture and nutrient regimes on the landscape, which, in turn, support a variety of vegetation zones and faunal habitats. Groundwater-dependent aquatic ecosystems, such as spring-fed streams that are fish spawning areas, or pothole lakes where salamanders breed, are significant to the overall health of the environment. Any perturbations to natural groundwater flow, or alterations to the water quality, would potentially affect the ecoregions.

Water use in the region is nearly evenly split between surface water (6.5 million m^3/year) and groundwater (6.3 million m^3/year), and is increasing at about 10% per year. Surface water is mostly accessed for industrial uses or for irrigation, whereas naturally filtered groundwater is favoured primarily for municipal supply/domestic consumption.

The Bow Valley-Kananaskis region appears to be quite capable of providing quality surface water and groundwater to its residents and industrial users for the foreseeable future. Difficulties finding water are most likely to occur where surficial aquifers are thin or drained, where there is a dependence on bedrock aquifers, or where population densities are high. Areas with limitations on yield include the Seebe district, the Knowlerville portion of Exshaw, and the southern ends of the Kananaskis and Spray valleys. Limitations occur at most locations outside of the valleys, but the mountainous areas are typically not developed because of the terrain. Exceptions are ski hills, alpine resorts and urban subdivisions of Canmore extending up the mountainsides.

While availability of groundwater is not generally a problem, seasonal variations may lead to shortages or flooding. For example, within the floodplain of the Bow River, and to a lesser extent the Kananaskis River, the water table is fairly shallow, but it may fluctuate significantly, particularly during spring runoff or after a major storm. It is also responsive to changes in river levels. Additionally, the Kananaskis River and the Spray Lakes Reservoir have controlled discharge that affects water levels in those valleys. Generally, though, groundwater flooding is not a major concern because urban development within the floodplain is limited to the town of Canmore.

Shortages in wells are not common, except in areas where aquifer yield is limited and demand is significant, such as parts of the Benchlands (Harvie Heights) or the Outwash Plain (Bow Valley Provincial Park). However, water shortages may occur when aquifers are stressed by concentrated demand and/or reductions in recharge.

Groundwater contamination is a serious potential problem that could impact the quality of drinking water, especially where demand is concentrated. Vulnerability to contamination varies, depending on the type of aquifer. Surficial aquifers are most vulnerable to contamination because undesirable substances dispersed into the environment will eventually leach into the ground and to the water table unless broken down. Confined aquifers are considerably better protected than unconfined aquifers; they are most vulnerable in their recharge areas or where the confining layer is breached through water or oil drilling and production or injection, or through changes in stratigraphy.

Surficial aquifers in the region, such as those along the Bow River, are mostly unconfined, with little to buffer them from activities at the land surface. Moreover, interaction between surface water and groundwater is pronounced, as recognized both in the Marmot Creek basin study and in water table monitoring wells in Canmore. Thus, contamination of these aquifers from surface spillage of pollutants is a distinct possibility, especially considering that the Canmore Corridor is a major transportation route.

To safeguard the integrity of the groundwater, hydrogeological preserves should be established and actively recognized as a vital component, rather than a by-product, of environmental protection. Emergency groundwater protection plans should also be devised and followed in the event of a contaminant spill.

Continued study of the groundwater resources of the Canmore Corridor and Northwestern Kananaskis Country is necessary to understand the vulnerability of aquifers to depletion and their potential response to natural and engineered changes in surface water discharge. Monitoring of the areas's aquifers—through Alberta Environment's groundwater monitoring well network—would help show the relationship between the water table and surface water levels. Further investigation would help determine the extent and productivity of aquifers (particularly the buried valley aquifer), through exploratory drilling, well monitoring, pump testing and water quality sampling.

Finally, the potential impacts to groundwater quantity and quality outside of this region should be considered. Groundwater supports base flow of the Bow River and its tributaries by redistributing precipitation from higher elevations through the subsurface. Further, the Bow River provides drinking water to the City of Calgary and irrigates farmland to the east of the city. Thus, impacts to the water resource in these headwaters may affect over one million users downstream. Also, impacts to the water resources in the Canmore Corridor and Northwestern Kananaskis Country might have farther-reaching effects on ecological systems, such as trout productivity in the Bow River.

Contents

Disclaimer and Citation .... *ii*
Executive Summary .... *iii*
Table of Contents .... *vii*
List of Tables .... *xi*
List of Figures .... *xii*

The Study

- Introduction 1-1
- Previous work 1-1
  - Mapping 1-1
  - GIC groundwater database 1-1
- Fieldwork, data compilation and mapping 1-2
  - Overview 1-2
  - Field-verification of known sites 1-2
  - Supplementary investigations 1-3
    - Exploratory drilling 1-3
    - Aerial surveys 1-3
  - Water quantity, quality and sources 1-3
    - Yields 1-3
    - Water chemistry 1-3
    - Stable isotope analysis 1-3
  - Surveying and mapping 1-4
    - Surveying 1-4
    - Database management 1-4
    - Mapping 1-5
    - Groundwater model for Canmore 1-5

Setting

- The study area 2-1
  - Canmore Corridor 2-1
  - Kananaskis Valley 2-2
  - Spray Lakes Valley 2-2
- Climate 2-3
- Topography and drainage 2-3
- Ecological regions 2-5
- Geology 2-5
  - Bedrock geology 2-5
  - Glacial geology and deposition 2-7
    - Bow Valley deposits 2-7
    - Kananaskis Valley deposits 2-7
    - Spray Lakes Valley deposits 2-8

Aquifers and Groundwater Chemistry

- Aquifers ... 3-1
  - Benchlands Aquifers ... 3-1
  - Outwash Plain Aquifer ... 3-2
  - Alluvial Fan and Valley Aquifers ... 3-2
    - Bow River Aquifer ... 3-2
    - Kananaskis Valley Aquifer ... 3-3
    - Spray Lakes Valley Aquifer ... 3-3
  - Calgary Buried Valley Aquifer ... 3-3
  - Bedrock Aquifers ... 3-4
- Groundwater chemistry ... 3-5
  - Total dissolved solids, major ions and groundwater types ... 3-5
  - Relative composition of groundwater —Piper and Schoeller plots ... 3-7
  - Drinking water quality ... 3-9

Springs

- Introduction ... 4-1
- Distribution and flow ... 4-2
- Water chemistry of springs ... 4-4
- Significant springs of the Bow Valley-Kananaskis region ... 4-5
  - Bow Valley ... 4-5
    - Many Springs ... 4-5
    - Bow Valley Provincial Park Lake Complex ... 4-6
    - Yamnuska Marl Spring ... 4-7
    - Railside Spring ... 4-7
    - Bow Flats ... 4-8
    - Grassi Lakes ... 4-8
    - Canmore Sulphur Spring ... 4-9
    - Fern Forest, Harvie Heights ... 4-9
  - Spray Lakes Valley ... 4-10
    - Spurling Spring ... 4-10
    - Watridge Karst Spring ... 4-10
  - Kananaskis Valley ... 4-10
    - POW Spring ... 4-10
    - Evan-Thomas Spring ... 4-10

Isotope Analysis

- Groundwater sampling program ... 5-1
  - Theory behind the sampling ... 5-1
- Isotopic analysis of groundwater in the Bow region ... 5-2
  - Regional meteoric water line ... 5-2
  - Altitudinal variations in δ values ... 5-2
  - Spatial variations in δ values ... 5-4
  - Seasonal changes in δD ... 5-4
  - General sample characteristics by location ... 5-4
  - Conclusions ... 5-5

Groundwater as an Ecological Resource

Groundwater interactions with the environment 6-1
Ecoregions 6-2
  Montane 6-2
  Subalpine and Alpine 6-2
Effects of groundwater flow on the distribution of flora and fauna 6-3
  Recharge areas 6-3
  Flow-through areas 6-5
  Discharge areas 6-5
    Aquatic and riparian areas 6-7
    Springs 6-7
Summary 6-8

Marmot Basin Hydrology Study

Watershed research program 7-1
Basin setting 7-1
Basin geology 7-2
Hydrology 7-2
Forestry and forest hydrology 7-3
Water balance 7-3
Groundwater monitoring 7-3
Hydrogeology 7-4
Conclusions 7-5

The Water Resource: Human Interactions

Current trends in water useage 8-1
Limitations to development 8-3
  Water quantity 8-3
  Water quality 8-3
  Flow variations 8-3
  Slope stability 8-3
Protecting the water resource 8-4
  Groundwater contamination 8-4
  Wellhead protection 8-5
  Hydrogeological preserves 8-5
Summary and recommendations 8-5

References 9-1

Acknowledgements

Appendices

Appendix A: Hydrogeological Maps
Appendix B: Water Chemistry
Appendix C: Cross Sections and Well Locations
Appendix D: Hydrogeology of Communities
Appendix E: Exploration Hole Logs
Appendix F: Alberta Environment Provincial Observation Wells

CD Pocket

Groundwater Database
Groundwater Model (Canmore)
Isotope Studies

List of Tables

Table 2.1 Geological formations 2-6

Table 3.1 Total dissolved solids concentrations in groundwater samples 3-5
Table 3.2 Average concentrations of major ions in groundwater samples 3-6
Table 3.3 Dominant groundwater types by region 3-6
Table 3.4 Major cations, anions and inorganics in drinking water 3-10
Table 3.5 Characteristics of trace elements in water supplies 3-11

Table 4.1 Distribution of springs located in the study area 4-2
Table 4.2 Sample spring types in the study area 4-3
Table 4.3 Variation in water characteristics in springs of the study area 4-4
Table 4.4 Variation in total dissolved solids in springs of the study area 4-4

Table 7.1 Alberta Environment monitoring wells 7-4

Table 8.1 Types of water use in Bow Valley and Kananaskis 8-2

List of Figures

Figure 1.1 Coverage and date of previous hydrogeological mapping 1-2
Figure 1.2 Locations of exploratory test holes and wells 1-3
Figure 1.3 GPS base stations and ranges 1-4

Figure 2.1 Location of Canmore Corridor and Northwestern Kananaskis Country, Alberta, showing municipal boundaries 2-1
Figure 2.2 Protected areas in the Canmore Corridor and Northwestern Kananaskis Country 2-2
Figure 2.3 The three valleys of the study area—Bow, Kananaskis and Spray Lakes—in their geologic setting 2-4

Figure 3.1 Types of aquifers in the study region 3-2
Figure 3.2 Comparison of water samples from Bow Valley communities using Scholler and Piper plots 3-8

Figure 4.1 Distribution of springs in the Canmore Corridor-Kananaskis region 4-2

Figure 5.1 Isotope samples at given locations plotted against the Calgary Meteoric Water Line 5-2
Figure 5.2 Model line for the study area vs. elevation 5-3
Figure 5.3 Deuterium excess against elevation 5-3
Figure 5.4 East-west trend in δD values (Bow Valley) 5-4

Figure 6.1 The three ecoregions of the study area 6-2
Figure 6.2 Generalized plant and animal assemblages for a groundwater recharge zone, Montane ecoregion 6-4
Figure 6.3 Generalized plant and animal assemblages for a groundwater recharge and lateral flow area, Subalpine ecoregion 6-4
Figure 6.4 Generalized plant and animal assemblages for a lateral groundwater flow area, Montane ecoregion 6-5
Figure 6.5 Generalized plant and animal assemblages for groundwater discharge areas, Montane ecoregion 6-6
Figure 6.6 Generalized plant and animal assemblages for groundwater discharge areas, Subalpine Ecoregion 6-6

Figure 7.1 Aerial view of the Marmot Creek Experimental Basin, looking west 7-2
Figure 7.2 Locations of wells in the Marmot Creek Experimental Basin 7-4

Figure 8.1 Surface and groundwater use in the Canmore region over the last two decades 8-1

The Study

Introduction

The Bow River Valley from Banff to Calgary has been one of the fastest growing regions of Alberta over the last twenty years. The Valley is expected to maintain its above-average growth in the foreseeable future as the vibrant economy of the Calgary area goes hand in hand with local, national and international appreciation of the Alberta Rockies. Growth has been particularly strong in the Canmore Corridor—that portion of the Bow Valley between the Stoney Indian Reserve and Banff National Park. The population growth of the Banff townsite has, in recent years, been superseded by the explosive growth of Canmore and its environs, fuelled by limits to urban and recreational developments within Banff National Park and the increasing popularity of Kananaskis Country as a destination. The Canmore Corridor will continue to be the locus of growth in permanent residents; moreover, recreational development will intensify the daily pressures of visitors and temporary residents on the Canmore Corridor and the adjoining northwestern portion of Kananaskis Country. Those pressures will include the increasing need for adequate supplies of quality drinking water, primarily from groundwater resources.

The purpose of this study was to collect baseline data and construct a model to provide an assessment of the groundwater capabilities of the Canmore Corridor and northwestern Kananaskis Country, including groundwater availability, quality, movement and interaction with the natural environment. The study was initiated in 1999 by the Hydrogeology Section of Alberta Environment under the auspices of the Western Economic Partnership Agreement (WEPA), which is a partnership between Western Economic Diversification Canada and Alberta Environment to support groundwater research in Alberta.

Initially, we gathered existing groundwater data from the study area and identified deficiencies, both in the extent of records and in their presentation. We then field-verified and improved the existing records, devised a pertinent database and mapping protocol, surveyed the area by air in late winter to detect additional discharge areas, and completed a supplementary drilling program that allowed us to understand groundwater flow and quality in the region and to develop a model for Canmore. Detailed methods are presented in the following sections of this chapter.

Previous work

Mapping

The hydrogeology of the region was originally mapped in three sections (Figure 1.1) by the Alberta Research Council in the late 1970s as part of a province-wide initiative. Two maps were published at a scale of 1:250,000, incorporating data from 132 water wells/springs in the Canmore Corridor for the Calgary-Golden (82-O) map sheet (Ozoray and Barnes, 1977) and 45 water wells/springs in the Kananaskis and Spray Lakes Valleys for the Kananaskis (82-J) map sheet (Borneuf, 1979). A more-detailed map, specific to the Canmore Corridor, was produced at 1:50,000 by Ceroici (1978), who analyzed approximately 85 water wells or test holes and 47 water samples, the same data used by Ozoray and Barnes. A significant number of test holes were drilled, and a survey of springs was undertaken by the Alberta Research Council as part of the program. Those original studies delineated geology, aquifer boundaries, groundwater yields and groundwater quality.

GIC groundwater database

The approximate number of groundwater records on file at Alberta Environment's Groundwater Information Centre (GIC) swelled from 175 in the mid 1970s to about 600 by the start of our study in 1999, including 440 well records and 160 chemical analyses. That increase provided improved coverage of the region's hydrogeology, but also indicated more competition for groundwater.

Fieldwork, data compilation and mapping

Overview

The thrust of our fieldwork was to identify, describe, accurately locate and catalogue the known wells, springs and test holes of the study area by field-verifying records from the GIC and by detecting lost or unrecorded sites. We surveyed 670 groundwater sites between 1999 and 2001. To locate well records that had been lost, misfiled or had inaccurate or inadequate locations, and to collect data on wells that had no existing record, we interviewed, door to door, the residents of Harvie Heights, Lac des Arcs, Exshaw and Dead Man's Flats.

We augmented our improved database in three ways: through exploratory drilling in areas where aquifer extent and properties were still largely unknown, through aerial surveying in late winter to identify springs and regions of groundwater discharge, and through water sampling of major ions, trace metals and isotopes.

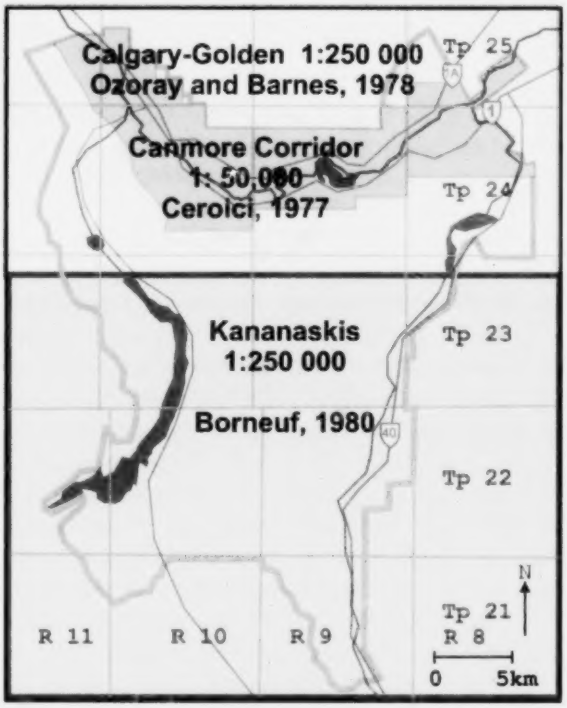


Figure 1.1 Coverage and date of previous hydrogeological mapping: Kananaskis mapsheet (green), Canmore Corridor (pink), Calgary-Golden (yellow).

Field-verification of known sites

Between June 1999 and October 2001, we confirmed the sites of 670 groundwater data locations, consisting of wells, test holes and springs. The sites were either previously documented in the GIC database, or were new sites identified by door-to-door survey, through word of mouth or encountered in the field. Field verification began as a door-to-door survey first in Harvie Heights, moving on to Dead Man's Flats, Lac des Arcs and finishing in Exshaw. Later, our survey moved to other parts of the Bow Valley and Kananaskis. GIC records were used to help identify wells outside of these communities.

The legal land descriptions given in the GIC database alone were rarely sufficient to locate sites on the ground. Original reports were combed for more site-specific information that could be garnered if available, such as owner's name and address, age of the well or a description of it, or lot and plan numbers. The search of the original files extended into Banff because several older wells from Harvie Heights had addresses reported as Banff. Well owners often gave a permanent residential address, rather than the well address, so original owners were contacted by phone where possible. Interviews with old-timers over the fence, or sitting down to tea and cookies, helped to match addresses to a number of well reports. In situations where wells were licensed, it was possible to obtain locations described in consulting reports. Door-to-door surveys in Harvie Heights, Dead Man's Flats, Exshaw and Lac des Arcs also helped to identify many wells never reported to the GIC.

At each well survey site, we determined the position with our GPS system. We measured the height, material and diameter of casings and whether or not the well was located in a pit. Water levels were recorded using a depth sounder when possible, and water samples were collected at sites where data were otherwise sparse. Additional details that were sought from residents or determined from examining the well included water quality or quantity, seasonal variations in flow, age of the well and so forth. We recorded the present owner's name and identified on a map the street and plan address and marked the location on a map. Often wells or test holes had been reclaimed, and the position was estimated as closely as possible.

At springs, we wrote a description of the spring and its surroundings and its interpreted source. We recorded the GPS position as closely as possible to the source position and water level. At most springs, we estimated the flow rate and collected water samples for routine analysis and isotope analysis.

Supplementary investigations

Exploratory drilling

To improve our understanding of the aquifers in the area, we drilled 21 investigative test holes over the three field seasons from 1999 to 2001: two located in Canmore, two in Exshaw, one near Lac des Arcs, one in Harvie Heights, one in Dead Man's Flats, seven in the region surrounding Seebe, and seven in the Spray Lakes Valley (Figure 1.2). Thirteen of the test holes were completed as wells.

The two wells completed in Canmore, and one each in Exshaw and Dead Man's Flats, were drilled to monitor a previously undiscovered aquifer that extends to a depth of at least 220 m below the Bow Valley. This high-yielding, high-quality water source was interpreted to be a western extension of the Calgary Buried Valley Aquifer (see page 3-3 and 3-4).

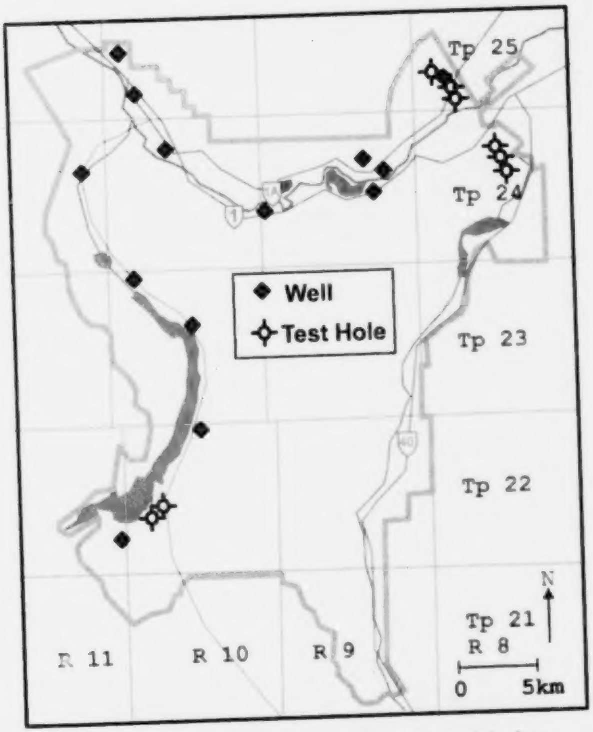


Figure 1.2 Locations of exploratory test holes and wells.

The well in Harvie Heights was drilled in response to recent concerns of residents about water levels running low or dry in late winter. We identified two aquifer zones and the depth to bedrock, allowing residents to plan future wells for maximum reliability. The well will remain for the monitoring of water levels.

Aerial surveys

We surveyed the study area by air from March 15 to 17, 2000, to identify major springs in areas with limited access. Significant groundwater discharge, particularly ponded areas along the Bow or Kananaskis rivers, was identifiable as open areas of water in otherwise snow- and ice-covered terrain. The locations were estimated on a map, and elevations were determined from a digital elevation model.

Water quantity, quality and sources

Yields

We determined transmissivity using pump test data and Jacob's modified non-equilibrium method. Aquifer yield was determined using the apparent Q_{20} method, commonly used in Alberta (Farvolden, 1961; Ozoray, 1977), in which the Q_{20}, or twenty-year-safe yield, is defined as the rate at which a well can be pumped continuously for twenty years without the water level dropping below the top of the aquifer if it is confined, or below the bottom saturated third of thickness of an unconfined aquifer.

Water chemistry

We collected water samples at 160 of the 670 survey sites for detailed water quality analyses of major ions and trace metals. These were combined with 258 existing water quality analyses of major ions taken from the GIC database. We classified groundwater chemistries into facies types according to dominant ions and compared them on Piper, Schoeller and Durov plots. We also mapped and contoured concentrations of total dissolved solids (TDS), except in areas such as the Spray Valley, where data were too sparse to contour; iron and nitrates, which tended to be site-specific, were simply plotted.

Stable isotope analysis

The proportions of ^{2}H to ^{1}H and ^{18}O to ^{16}O in a water sample may often be used to determine the origin of the water and its interactions with its surrounding environment. Thus, we collected 130 water samples during the field-verified survey, mainly from wells and springs, but also from snow, rain and surface water to examine these isotopes. Of the samples collected, 86 were from the Bow Valley, 27 from the Kananaskis Valley and 17 from the Spray Lakes Valley. Most were groundwater, apart from three surface water, one rain and two snow samples from the Bow Valley, six snow samples from the Kananaskis Valley and one snow sample from the Spray Lakes Valley.

Surveying and mapping

Surveying

Records in the GIC had been assigned legal land descriptions within the Dominion Land Survey (DLS) system, usually to the nearest quarter section, and rarely to the nearest Legal Subdivision (LSD) or Section. However, we devised a new surveying protocol to pinpoint well locations because the old DLS system was inadequate, particularly for mapping aquifers in mountainous terrain. While the system worked well on the prairies—where the DLS system was carved onto the landscape as numbered grid roads—in the mountains, no physical references were visible, so the DLS location was often guesswork for drillers and residents when they filled out the forms. Also, in the mountains, settlement is clustered in the valleys, unlike the farms scattered across the expansive prairie; thus, within Harvie Heights, an area of high well density, 75 wells in the same quarter section have the identical DLS reference. Further, a potential location error of ½ mile (800 m) exists within a quarter section, making accurate locations even less reliable.

Vertically, the DLS was another problem. While relief on the prairies is subdued and wells are relatively deep, in the mountains vertical relief within a quarter section can vary up to 300 m and wells are relatively shallow. Thus, elevations were rarely reported on GIC records or were often estimated, with significant error, from topographic maps.

We determined positions with an *Ashtec Locus* geographical positioning system (GPS) capable of recording latitude, longitude and elevation to within ten centimetres. It required unobstructed sky, so an offset was made where wells were located under buildings or were blocked by structures. GPS base stations were located at the Provincial Building in Canmore, the M.D. of Bighorn Administration Building in Exshaw and the Emergency Services Centre Helipad in Kananaskis (Figure 1.3). With a range of 20 km each, they were placed strategically to cover the 200 km² area of the Canmore Corridor. Data collected by the roaming GPS receivers and the nearest base station were downloaded daily onto a laptop and processed using *Ashtec Locus* software to obtain the positions. Each station's position was then verified against Alberta survey benchmarks.

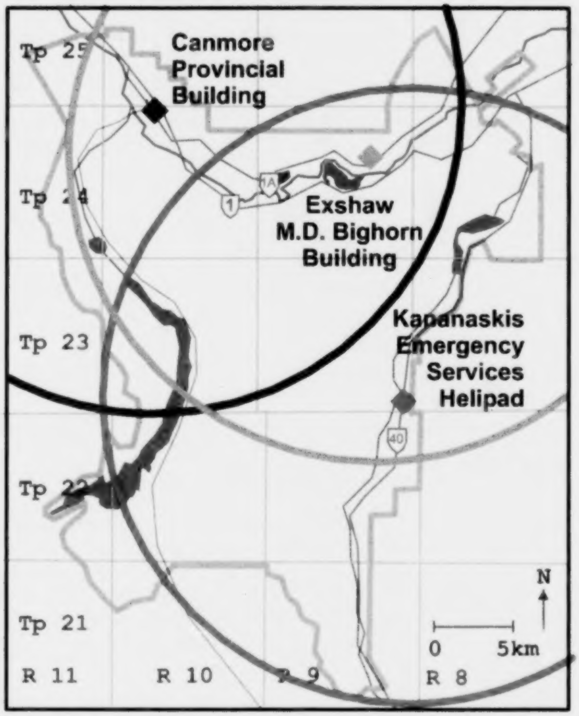

Tp 25
Canmore Provincial Building
Tp 24
1A
1
Exshaw M.D. Bighorn Building
Tp 23
Kananaskis Emergency Services Helipad
40
Tp 22
Tp 21
N
0
5km
R 11
R 10
R 9
R 8

Figure 1.3 GPS base stations and ranges.

Database management

We designed a *Microsoft Access* database to store, manage and present the existing and new data. Drilling and chemistry records from the GIC database were transferred electronically, as were chemistry results stored in Alberta Environment's Environmental Management System (EMS). Field-collected information was entered manually.

Each of the 850 records was assigned a unique four-digit "WEPA number", consecutively in the order of field verification. A secondary unique number was the "GIC number", assigned by the Groundwater Information Centre to records obtained from their database. However, 178 sites were not field-verified, because the location was not specific enough to find the well or spring, the well had been reclaimed and no one remembered the location, or the owner was unavailable; they were each assigned a four-digit WEPA number beginning with the number 9. If the location of an unsurveyed site were reasonably known, its latitude, longitude and elevation was estimated from air photo data in *ESRI ArcView* format and a digital elevation model. The remaining records were assigned a position in the centre of the designated quarter section. Within each record, data were organized by location, ownership, well construction details, lithology, chemistry, pump tests and comments.

Mapping

We used the information from each record to produce maps featuring bedrock topography, drift thickness, aquifer distribution, groundwater flow, aquifer yield and groundwater chemistry.

We determined bedrock topography and drift thickness with a digital elevation model of the area, and known depths to bedrock from drilling information. We used lithologies to delineate aquifer extent, and non-pumping water levels from drilling reports were used to create a potentiometric map.

Groundwater model for Canmore

To simulate the natural groundwater balance in the Canmore region, we constructed a three-dimensional model of groundwater flow of the unconsolidated valley aquifer for the area surrounding the Town of Canmore. It was built in *Modflow*, which is a cell-based three-dimensional finite-difference groundwater flow model developed by the United States Geological Survey. The version we used was developed by Waterloo Hydrogeoloic. It permits planners to simulate the effects of environmental impacts on the groundwater system, including the effects of withdrawals on surrounding users, or the potential spread of a contaminant spill.

Setting

The study area

The study area includes the Canmore Corridor—that portion of the Bow River Valley between Banff National Park and the Stoney Indian Reserve—and the adjacent northwestern portion of Kananaskis Country, bounded by Banff National Park, Peter Lougheed Provincial Park and Elbow-Sheep Wildland Provincial Park. Northwestern Kananaskis Country comprises two distinct areas: Kananaskis Valley and Spray Lakes Valley. Together with the Canmore Corridor, they constitute historical, geological, ecological and culturally distinct regions.

The study area (Figure 2.1) has an irregular boundary contained wholly within Townships 21 to 25, Ranges 8 to 11 West of the 5th Meridian under the Dominion Land Survey System, or between 50° 45' and 51° 10' North latitude and 115° 00' and 115° 30' West longitude. It covers portions of the 82O-03 and 82J-14 National Topographic System map sheets.

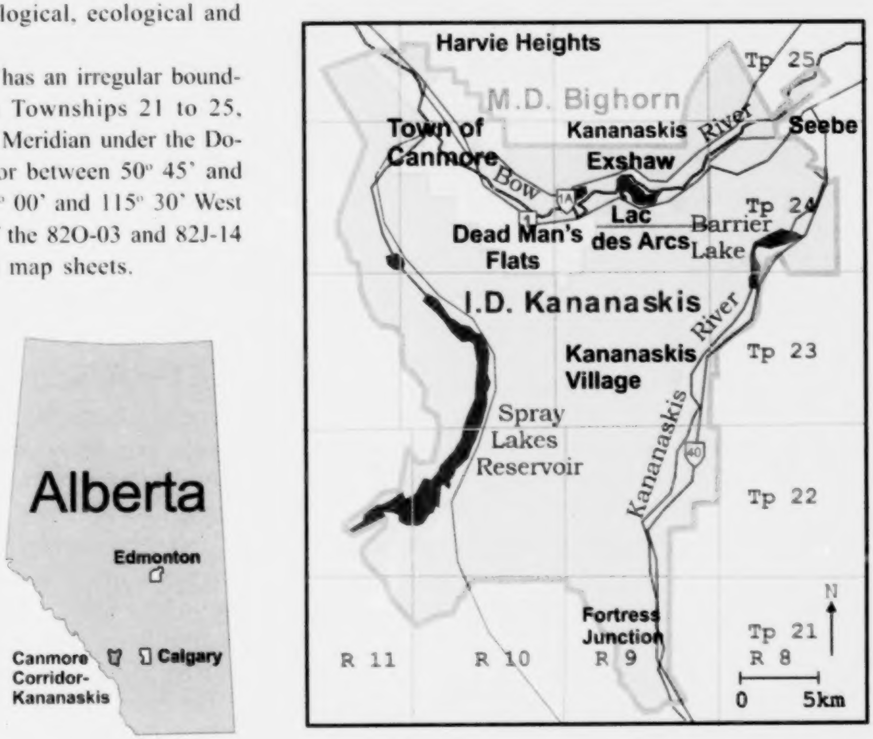

Alberta
Edmonton
Canmore Corridor-Kananaskis
Calgary
Harvie Heights
Tp 25
M.D. Bighorn
Town of Canmore
Kananaskis
River
Seebe
Exshaw
Bow
1A
1
Lac des Arcs
Tp 24
Barrier Lake
Dead Man's Flats
I.D. Kananaskis
River
Kananaskis Village
Tp 23
Spray Lakes Reservoir
Kananaskis
40
Tp 22
Fortress Junction
N
Tp 21
R 11
R 10
R 9
R 8
0
5km

Figure 2.1 Location of Canmore Corridor and Northwestern Kananaskis Country, Alberta, showing municipal boundaries.

Canmore Corridor

(200 km²; 11,400 residents)

The Canmore Corridor is a 25-km stretch of the Bow River Valley that cuts through the front ranges of the Rocky Mountains between Banff National Park and the Stoney Indian Reserve. It is located within the Municipal District (M.D.) of Bighorn #8. This corridor is a major transportation route, hosting the Trans-Canada Highway, secondary Highway 1A, the Canadian Pacific Railway main line and the Trans-Canada Trail. Over five million visitors a year pass through the Canmore Corridor to Banff National Park.

The Town of Canmore (pop. 10,500) is the population and service centre of the region, whereas Exshaw (pop. 346) is the industrial and mining hub. Other settlements include the hamlets of Lac des Arcs (pop. 178), Harvie Heights (pop. 155), Dead Man's Flats (pop. 104) and Seebe (pop. 80), and the community of Kananaskis (pop. 15) (Alberta Census, 2000.) (The latter, situated 3 km east of Exshaw, should not be confused with the Kananaskis Village resort in the Kananaskis Valley.) Census numbers do not include seasonal residents or visitors.

Setting

The study area

The study area includes the Canmore Corridor—that portion of the Bow River Valley between Banff National Park and the Stoney Indian Reserve—and the adjacent northwestern portion of Kananaskis Country, bounded by Banff National Park, Peter Lougheed Provincial Park and Elbow-Sheep Wildland Provincial Park. Northwestern Kananaskis Country comprises two distinct areas: Kananaskis Valley and Spray Lakes Valley. Together with the Canmore Corridor, they constitute historical, geological, ecological and culturally distinct regions.

The study area (Figure 2.1) has an irregular boundary contained wholly within Townships 21 to 25, Ranges 8 to 11 West of the 5th Meridian under the Dominion Land Survey System, or between 50° 45' and 51° 10' North latitude and 115° 00' and 115° 30' West longitude. It covers portions of the 82O-03 and 82J-14 National Topographic System map sheets.

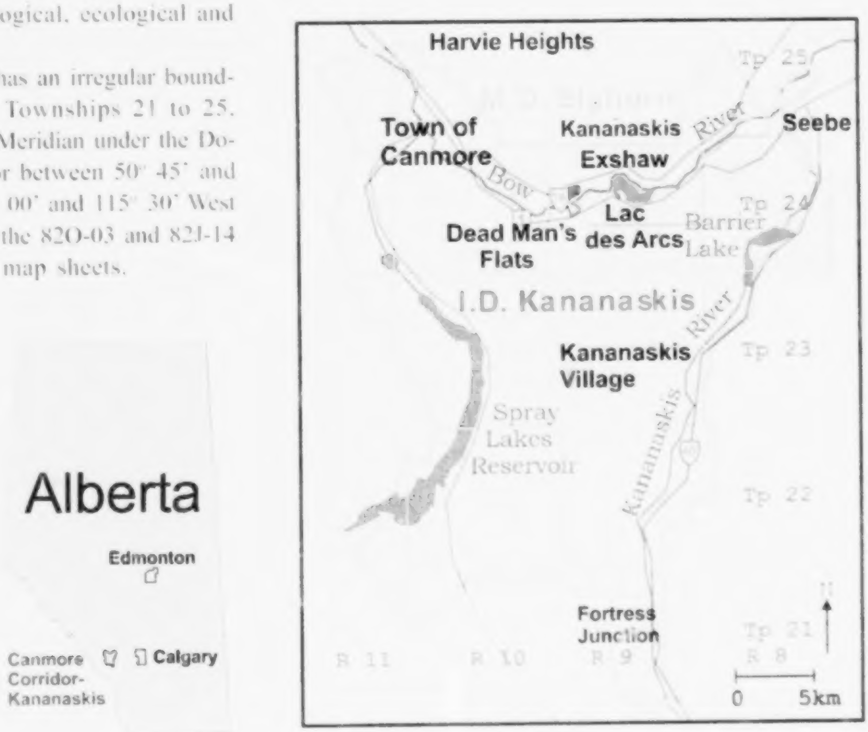

Alberta
Edmonton
Canmore Corridor-Kananaskis
Calgary
Harvie Heights
M.D. Bighorn
Tp 25
Town of Canmore
Kananaskis
Exshaw
Seebe
Bow
River
Lac des Arcs
Dead Man's Flats
Barrier Lake
Tp 24
I.D. Kananaskis
Kananaskis River
Kananaskis Village
Tp 23
Spray Lakes Reservoir
Tp 22
Fortress Junction
Tp 21
R 11
R 10
R 9
R 8
N
0
5km

Figure 2.1 Location of Canmore Corridor and Northwestern Kananaskis Country, Alberta, showing municipal boundaries.

Canmore Corridor

(200 km^2; 11,400 residents)

The Canmore Corridor is a 25-km stretch of the Bow River Valley that cuts through the front ranges of the Rocky Mountains between Banff National Park and the Stoney Indian Reserve. It is located within the Municipal District (M.D.) of Bighorn #8. This corridor is a major transportation route, hosting the Trans-Canada Highway, secondary Highway 1A, the Canadian Pacific Railway main line and the Trans-Canada Trail. Over five million visitors a year pass through the Canmore Corridor to Banff National Park.

The Town of Canmore (pop. 10,500) is the population and service centre of the region, whereas Exshaw (pop. 346) is the industrial and mining hub. Other settlements include the hamlets of Lac des Arcs (pop. 178), Harvie Heights (pop. 155), Dead Man's Flats (pop. 104) and Seebe (pop. 80), and the community of Kananaskis (pop. 15) (Alberta Census, 2000.) (The latter, situated 3 km east of Exshaw, should not be confused with the Kananaskis Village resort in the Kananaskis Valley.) Census numbers do not include seasonal residents or visitors.

In the late 1970s, the economies of Canmore and Exshaw were still dependent on mining, with Canmore facing imminent closure of its remaining coal mines and an uncertain future. Proposals were put forward to redevelop the Bow Valley as a recreational area hosting a series of resort and acreage communities. Kananaskis Country was newly designated, but the Kananaskis and Spray valleys were still fairly inaccessible and undeveloped. By the year 2000, the region had become a tourist destination. The populations of nearby Banff and Calgary had doubled and Canmore's population had grown six-fold, from 1700 permanent residents in 1977 to 10,500 in 2000. That growth has been accentuated by development restrictions in Banff. Protected areas include the Canmore Nordic Centre Provincial Park, which hosted events for the 1988 Winter Olympic Games, and portions of Bow Valley Wildland Park and Bow Valley Provincial Park (Figure 2.2).

Kananaskis Valley

(345 km^2; 125 residents)

The Kananaskis Valley between the Stoney Indian Reserve and Peter Lougheed Park is traversed by Highway #40. There are no incorporated communities in the valley, the main service centre being the Kananaskis Village resort (pop. 117) (Alberta Census, 2000). The resort area is home to the Nakiska Ski Hill (which hosted events for the 1988 Winter Olympic games), the Lodge at Kananaskis, a youth hostel and the Emergency Services Centre. A gas station and store are located at Fortress Junction, and The University of Calgary operates a field station near Barrier Lake. The valley hosts day-use facilities, campgrounds and guest ranches, so that even though the resident population is small, over two million visitors come to the Kananaskis region each year.

The Kananaskis Valley remained largely undeveloped forest reserve until 1977, when Kananaskis Country was designated by the Alberta Government as a multi-use recreation area. The gravel forestry road was then replaced by Highway 40, initiating the redevelopment of the valley. Most of the region is now protected lands, including Evan-Thomas Recreation Area and portions of Bow Valley Wildland Park, Spray Valley Provincial Park and Bow Valley Provincial Park.

Flow on the Kananaskis River is controlled by TransAlta Utilities, with dams upstream at the Kananaskis Lakes and at Barrier Lake.

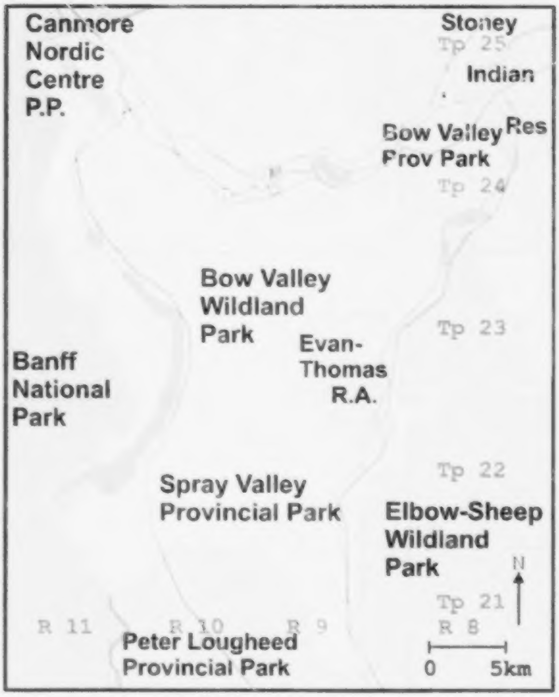


Figure 2.2 Protected areas in the Canmore Corridor and Northwestern Kananaskis Country.

Spray Lakes Valley

(230 km^2; 0 residents)

The Spray Lakes Valley within Kananaskis Country extends from Whiteman's Pass, just south of Canmore, to Peter Lougheed Provincial Park. A prominent feature of the valley is a hydroelectric complex operated by TransAlta Utilities, consisting of the Spray Lakes Reservoir, Goat Pond Reservoir and a canal system that diverts water north through Whiteman's Pass to the Bow River. The Spray Lakes Reservoir is the largest body of water in the region.

The Spray Lakes Valley is accessed by the Smith-Dorrien Trail, a gravel road that joins Canmore and Peter Lougheed Provincial Park. The area hosts a seasonal tourist lodge, a campground and several day-use sites. Most of the valley is protected by Spray Valley Provincial Park or portions of Bow Wildland Park.

Together, the Kananaskis and Spray Lakes valleys are within the Kananaskis Improvement District municipal government.

In the late 1970s, the economies of Canmore and Exshaw were still dependent on mining, with Canmore facing imminent closure of its remaining coal mines and an uncertain future. Proposals were put forward to redevelop the Bow Valley as a recreational area hosting a series of resort and acreage communities. Kananaskis Country was newly designated, but the Kananaskis and Spray valleys were still fairly inaccessible and undeveloped. By the year 2000, the region had become a tourist destination. The populations of nearby Banff and Calgary had doubled and Canmore's population had grown six-fold, from 1700 permanent residents in 1977 to 10,500 in 2000. That growth has been accentuated by development restrictions in Banff. Protected areas include the Canmore Nordic Centre Provincial Park, which hosted events for the 1988 Winter Olympic Games, and portions of Bow Valley Wildland Park and Bow Valley Provincial Park (Figure 2.2).

Kananaskis Valley

(345 km^2; 125 residents)

The Kananaskis Valley between the Stoney Indian Reserve and Peter Lougheed Park is traversed by Highway #40. There are no incorporated communities in the valley, the main service centre being the Kananaskis Village resort (pop. 117) (Alberta Census, 2000). The resort area is home to the Nakiska Ski Hill (which hosted events for the 1988 Winter Olympic games), the Lodge at Kananaskis, a youth hostel and the Emergency Services Centre. A gas station and store are located at Fortress Junction, and The University of Calgary operates a field station near Barrier Lake. The valley hosts day-use facilities, campgrounds and guest ranches, so that even though the resident population is small, over two million visitors come to the Kananaskis region each year.

The Kananaskis Valley remained largely undeveloped forest reserve until 1977, when Kananaskis Country was designated by the Alberta Government as a multi-use recreation area. The gravel forestry road was then replaced by Highway 40, initiating the redevelopment of the valley. Most of the region is now protected lands, including Evan-Thomas Recreation Area and portions of Bow Valley Wildland Park, Spray Valley Provincial Park and Bow Valley Provincial Park.

Flow on the Kananaskis River is controlled by TransAlta Utilities, with dams upstream at the Kananaskis Lakes and at Barrier Lake.

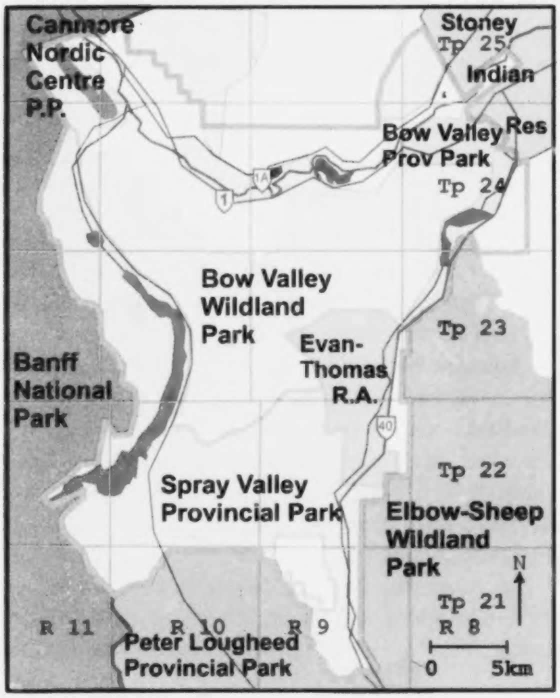


Figure 2.2 Protected areas in the Canmore Corridor and Northwestern Kananaskis Country.

Spray Lakes Valley

(230 km^2; 0 residents)

The Spray Lakes Valley within Kananaskis Country extends from Whiteman's Pass, just south of Canmore, to Peter Lougheed Provincial Park. A prominent feature of the valley is a hydroelectric complex operated by TransAlta Utilities, consisting of the Spray Lakes Reservoir, Goat Pond Reservoir and a canal system that diverts water north through Whiteman's Pass to the Bow River. The Spray Lakes Reservoir is the largest body of water in the region.

The Spray Lakes Valley is accessed by the Smith-Dorrien Trail, a gravel road that joins Canmore and Peter Lougheed Provincial Park. The area hosts a seasonal tourist lodge, a campground and several day-use sites. Most of the valley is protected by Spray Valley Provincial Park or portions of Bow Wildland Park.

Together, the Kananaskis and Spray Lakes valleys are within the Kananaskis Improvement District municipal government.

Climate

Under the Koeppen classification system, Longley (1972) designates the area as a microthermal climate with short, cool summers. Long-term climate data from Environment Canada weather stations at Bow Valley Provincial Park, Exshaw and in the Kananaskis region show that the mean annual temperature is near 3° C in the Bow Valley and between 1° and 3° C in the Kananaskis Valley.

Pacific air masses from the west dominate the higher elevations, where they provide most of the region's precipitation as winter snowpack on the mountains. The orographic effect on the prevailing westerlies creates a rainshadow on the leeward sides of the ranges. Conversely, eastern continental systems bring rainfall and a weaker reverse orographic effect in summer. Dry Chinook winds from the west and dry interior continental air masses from the east preferentially settle in the valley bottoms. North-facing slopes tend to be cool and moist, while exposed south-facing slopes are warmer and drier (Strong, 1992). Summers are short, particularly at higher elevations and on north-facing slopes. Climate can vary considerably in a small area, as cold air often drains from higher slopes at night.

Precipitation in the Bow Valley follows a continental pattern and is heaviest in July. It varies from 400 to 550 mm, with potential evapotranspiration in the same range, making the area marginally semi-arid. The Montane of the Bow Valley receives 20 Chinook days a year, but at higher elevations this drops to less than 15 for Subalpine, and less than 5 for Alpine (O'Leary, 1988). Drying Chinook winds can quickly remove snow cover from unprotected areas of the valley bottom, and potential evapotranspiration may exceed precipitation in June, July and August. Freezing temperatures occur in all months, but are least frequent in July.

The Subalpine and Alpine slopes and peaks receive more winter precipitation than any other region of Alberta. Total precipitation has been measured in the range of 650 to 750 mm in the Kananaskis region (Environment Canada current data), but may vary considerably with site conditions. Storr (1967) reported precipitation in the range of 900 to 1140 mm in the upper part of the Marmot Creek Basin in the Kananaskis Valley. Between 50 and 75% of precipitation falls as snow, the percentage increasing with elevation. Cold winters and cool summers limit evapotranspiration, estimated at less than 50% of precipitation (Storr, 1967), making the mountains the primary watersheds for the valley and for the prairies to the east (Alberta Forestry, Lands & Wildlife, 1988).

Topography and drainage

Elevations in the area range from a high of over 3000 m above sea level to a low of 1250 m. The highest elevations are within the Kananaskis Range in the southern part of the area; five peaks exceed 3000 m elevation, the highest being Mount Galatea at 3185 m. The lowest elevations are in the Bow Valley.

The Bow Valley descends from 1320 m near Harvie Heights to 1250 m near Seebe, the lowest point in the study area. The Kananaskis Valley is higher, dropping from 1600 m near Fortress Junction to 1450 m near Kananaskis Village to 1280 m near the confluence of the Kananaskis and Bow Rivers. The Spray Lakes Valley is the highest, sloping from 1710 m at the Spray Lakes Reservoir to 1650 m near Whiteman's Pass, just above Canmore; its lowest elevation is, therefore, higher than the highest elevations in the Kananaskis and Bow valleys.

The western Bow Valley is carved into soft Cretaceous shale beds of the Mount Allan Syncline, where it forms an open valley 5 km wide with a broad floodplain (Figure 2.3). It then turns to the northeast where it cuts across the Fairholme Range. At The Gap, the valley narrows to 1.5 km and is flanked by steep, rocky sides. At the eastern end of the corridor, the mountains pull back along the McConnell thrust fault and the valley broadens into a 7-km wide plain adjoining the foothills, underlain by Cretaceous shale and sandstone. The Bow River starts down-cutting at this point, until it flows through a bedrock canyon near Seebe.

The Kananaskis River occupies the Kananaskis Valley, flowing north from Peter Lougheed Park and northeast to Seebe, where it joins the Bow River. The south end of the valley tends to be narrow, only 1.5

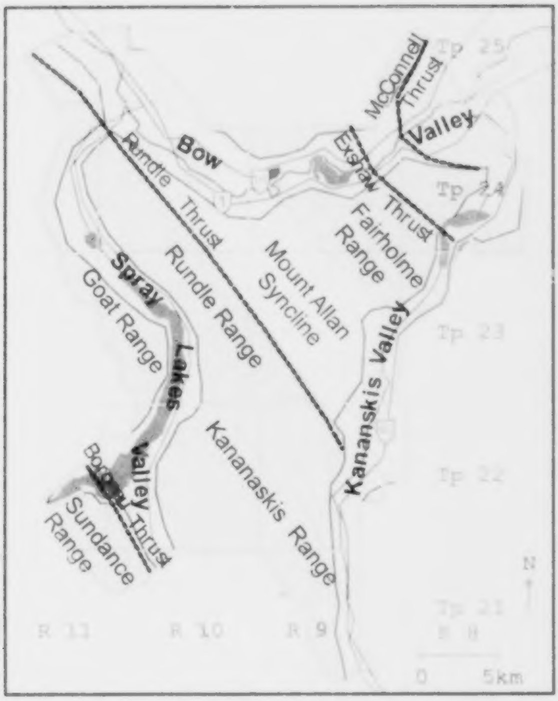


Figure 2.3 The three valleys of the study area—Bow, Kananaskis and Spray Lakes—in their geologic setting.

km wide, flanked by steep mountainsides of Paleozoic limestone and dolomite of the Rundle and Opal Ranges. The valley broadens to 3 km wide from Evan-Thomas Creek to Kananaskis Village and Marmot Basin, where it occupies the Mt. Allan Syncline, before narrowing to 1.5 km as it veers to the northeast across the Fairholme Range. The Kananaskis River has cut a canyon into Cretaceous bedrock near its confluence with the Bow River at Seebe.

The Spray Lakes Valley is dominated by the Spray Lakes Reservoir and is approximately 1.5 km wide for most of its length. At its south end, where it intercepts the Borgeau fault and the Smith-Dorrien Valley, it is fairly open, becoming around 3 km wide.

The Canmore Corridor-Kananaskis region lies entirely within the Bow River Basin. Both the Kananaskis and Spray Lakes valleys drain northward to the Bow, and the Canmore Corridor is wholly within the valley of the Bow River, which itself originates farther northwest in Banff National Park. The combined drainages flow east onto the prairies, where the Bow River eventually merges with the Oldman River to form the South Saskatchewan River.

The Bow River above Seebe drains an area of 5170 km^2, although the drainage area of our study area between Banff and Seebe is only 2960 km^2 (Alberta Environment, Hydrology Section). The long-term mean monthly discharge of the Bow River at Banff varies from a low of 7.6 m^3/s in March to a high of 127 m^3/s in June, averaging 40 m^3/s over the year (Alberta Environment, 1982). It takes half a day for water to flow from Banff to Seebe, where the long-term mean monthly discharge varies from a low of 19.6 m^3/s in March to a high of 245 m^3/s in June, averaging 79.9 m^3/s over the year. At Seebe, the Bow River is controlled by the Horseshoe Falls and Kananaskis dams, each of which has negligible live storage (storage that can be released by opening the dam).

The Kananaskis River rises in Peter Lougheed Park and drains 935 km^2 before joining the Bow River at Seebe; however, the basin area between Pocaterra in Peter Lougheed Park and Seebe is only 575 km^2 (Alberta Environment, 1982). The long-term mean monthly discharge at Seebe ranges from a low of 3.4 m^3/s in January/February to a high of 49.2 m^3/s in June, averaging 15.7 m^3/s for the year (Alberta Environment, 1982). Flow of the Kananaskis River is controlled by dams at Pocaterra, forming the Kananaskis Lakes in Peter Lougheed Provincial Park, and at Barrier Lake. The Kananaskis Lakes Reservoir was completed in 1936 and has 134,500 acre-feet of live storage; the smaller Barrier Reservoir was completed in 1947, with 20,000 acre-feet of live storage.

Within the Spray Lakes Valley, natural drainage at the north end was historically via Goat Creek to Banff; at the south end, drainage was down the Spray River to the Bow River at Banff. The Construction of the Spray Lakes Reservoir in 1950 merged the two basins. Through the Reservoir, the valley now has two outlets: the Spray River flows from the Canyon Dam at the south end of the reservoir, while the Three Sisters Dam at the north end diverts water into a canal system that drains north through Goat Pond, Whiteman's Pond, over Whiteman's Pass into the Rundle Forebay and from there to the Bow River. At Whiteman's Pass, the water drops 370 m, generating 142,200 kW of electricity.

The drainage area of the Spray Lakes Reservoir is 481 km^2, extending beyond the Spray Lakes Valley into Peter Lougheed Park and Banff National Park. This valley has the lowest flow rates of the three in our study area: long-term mean monthly discharges from the Spray Power Diversion at Canmore varies from a low of 7.35 m^3/s in October to a high of 15.4 m^3/s in January, averaging 11.3 m^3/s for the year.

The importance of the region's contribution to flow in the South Saskatchewan River drainage basin was

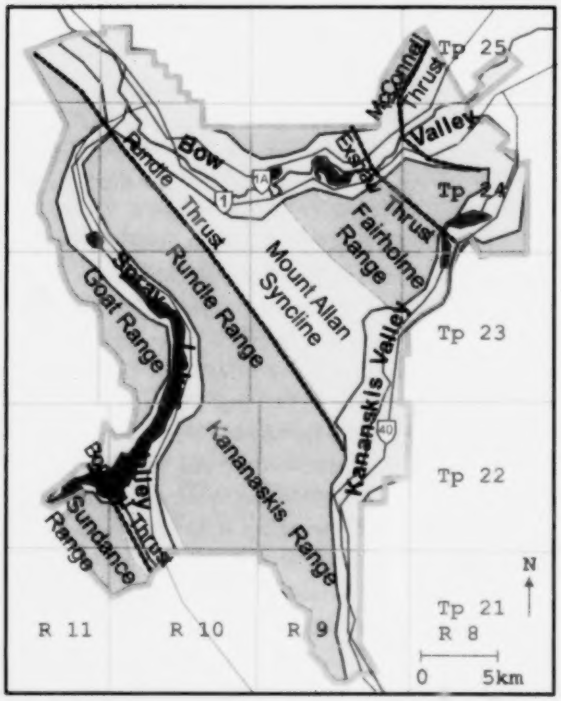


Figure 2.3 The three valleys of the study area—Bow, Kananaskis and Spray Lakes—in their geologic setting.

km wide, flanked by steep mountainsides of Paleozoic limestone and dolomite of the Rundle and Opal Ranges. The valley broadens to 3 km wide from Evan-Thomas Creek to Kananaskis Village and Marmot Basin, where it occupies the Mt. Allan Syncline, before narrowing to 1.5 km as it veers to the northeast across the Fairholme Range. The Kananaskis River has cut a canyon into Cretaceous bedrock near its confluence with the Bow River at Seebe.

The Spray Lakes Valley is dominated by the Spray Lakes Reservoir and is approximately 1.5 km wide for most of its length. At its south end, where it intercepts the Borgeau fault and the Smith-Dorrien Valley, it is fairly open, becoming around 3 km wide.

The Canmore Corridor-Kananaskis region lies entirely within the Bow River Basin. Both the Kananaskis and Spray Lakes valleys drain northward to the Bow, and the Canmore Corridor is wholly within the valley of the Bow River, which itself originates farther northwest in Banff National Park. The combined drainages flow east onto the prairies, where the Bow River eventually merges with the Oldman River to form the South Saskatchewan River.

The Bow River above Seebe drains an area of 5170 km^2, although the drainage area of our study area between Banff and Seebe is only 2960 km^2 (Alberta Environment, Hydrology Section). The long-term mean monthly discharge of the Bow River at Banff varies from a low of 7.6 m^3/s in March to a high of 127 m^3/s in June, averaging 40 m^3/s over the year (Alberta Environment, 1982). It takes half a day for water to flow from Banff to Seebe, where the long-term mean monthly discharge varies from a low of 19.6 m^3/s in March to a high of 245 m^3/s in June, averaging 79.9 m^3/s over the year. At Seebe, the Bow River is controlled by the Horseshoe Falls and Kananaskis dams, each of which has negligible live storage (storage that can be released by opening the dam).

The Kananaskis River rises in Peter Lougheed Park and drains 935 km^2 before joining the Bow River at Seebe; however, the basin area between Pocaterra in Peter Lougheed Park and Seebe is only 575 km^2 (Alberta Environment, 1982). The long-term mean monthly discharge at Seebe ranges from a low of 3.4 m^3/s in January/February to a high of 49.2 m^3/s in June, averaging 15.7 m^3/s for the year (Alberta Environment, 1982). Flow of the Kananaskis River is controlled by dams at Pocaterra, forming the Kananaskis Lakes in Peter Lougheed Provincial Park, and at Barrier Lake. The Kananaskis Lakes Reservoir was completed in 1936 and has 134,500 acre-feet of live storage; the smaller Barrier Reservoir was completed in 1947, with 20,000 acre-feet of live storage.

Within the Spray Lakes Valley, natural drainage at the north end was historically via Goat Creek to Banff; at the south end, drainage was down the Spray River to the Bow River at Banff. The Construction of the Spray Lakes Reservoir in 1950 merged the two basins. Through the Reservoir, the valley now has two outlets: the Spray River flows from the Canyon Dam at the south end of the reservoir, while the Three Sisters Dam at the north end diverts water into a canal system that drains north through Goat Pond, Whiteman's Pond, over Whiteman's Pass into the Rundle Forebay and from there to the Bow River. At Whiteman's Pass, the water drops 370 m, generating 142,200 kW of electricity.

The drainage area of the Spray Lakes Reservoir is 481 km^2, extending beyond the Spray Lakes Valley into Peter Lougheed Park and Banff National Park. This valley has the lowest flow rates of the three in our study area: long-term mean monthly discharges from the Spray Power Diversion at Canmore varies from a low of 7.35 m^3/s in October to a high of 15.4 m^3/s in January, averaging 11.3 m^3/s for the year.

The importance of the region's contribution to flow in the South Saskatchewan River drainage basin was recognized by an extensive headwaters study of the Marmot Creek drainage basin near Kananaskis Village that ran from 1963 to 1986, with an emphasis on the impact of deforestation on basin yield. Among their findings, researchers reported that precipitation and snowpack increased with elevation, peak runoff occurred in May and June, that appreciable groundwater storage and flow was likely taking place, and that logging resulted in a minor increase in basin yield (Hydrocon, 1985).

Ecological regions

The Bow Valley-Kananaskis region hosts three natural subregions or ecoregions according to ecological land classification: Montane, Subalpine and Alpine (see Chapter 6 for more detail). The regions are distinguished by characteristic assemblages of natural vegetation, climate and, to a lesser degree, soils. Climate and vegetation can vary considerably within a natural subregion; however, temperature and precipitation regimes, together with distinct ecological relationships and repeated association of vegetation, distinguish adjoining regions (Strong, 1992).

The Montane natural subregion occupies the valley bottom and lower mountain slopes and terraces of the Bow Valley and lower Kananaskis Valley. It forms a varied mix of grasslands, wetlands and open forests of Douglas fir, aspen, lodgepole pine and white spruce. It has the mildest and driest climate of the three subregions. The mixture of open and forested terrain, mild climate, abundance of shelter and food, combined with its accessibility in the valley bottom, causes it to be favoured by wildlife, as well as by human settlement. The Montane natural subregion is rare in Alberta, constituting less than 1% of the province and occupying a few mountain valley and foothill locations. It is also the most threatened by development.

The Subalpine natural subregion occupies the mid to upper mountain slopes of the Bow Valley and the slopes and bottoms of the upper Kananaskis and Spray Lakes valleys. It is characterized by closed mossy forests of lodgepole pine, Engelmann spruce and subalpine fir, and sometimes grasslands on steep south- or west-facing slopes.

The Alpine natural subregion occurs above the subalpine, where contiguous forest stops and isolated stands of trees begin. The land shows barren rock or hosts small shrubs, grasses and other small forbs.

Geology

Bedrock geology

The Rocky Mountains and foothills form the western margin of the Alberta sedimentary basin as a belt of folds and thrust faults. The regional section is cut by a series of overlapping thrust faults, which tend to flatten and merge at depth. Local terrain is controlled by bedrock lithology, bedrock structure and faulting, glaciation patterns and erosion. Folding and faulting of strata, sliced by rugged terrain, expose repeating and broken sequences of sedimentary strata ranging in age from Cambrian to Cretaceous (Table 2.1) (Hamilton et al., 1997; Ollerenshaw, 1975; Edwards, 1991).

The foothills region, found at the eastern end of the Bow Valley, is separated from the front ranges by the McConnell Thrust Fault. Upper Cretaceous strata are exposed near Seebe. The Kananaskis dam at Seebe is constructed on gently west-dipping Cardium Formation sandstone and conglomerate. Immediately west of the dam, overlying Wabiabi Formation shales are excavated by Lafarge at their Seebe pit as a component of cement. Cross-bedded sandstones of the Chungo member of the Wabiabi formation are quarried by Lafarge at the base of Mount Yamnuska.

The Fairholme, Rundle and Goat front ranges are formed of steeply west-dipping strata within the McConnell thrust sheet (Figure 2.3) and Appendix. The McConnell Thrust fault places Cambrian Eldon Formation limestone over top of the Upper Cretaceous sandstone and shale. The fault is a significant landmark, forming dramatic 100-m cliff faces stretching across Mount (Laurie) Yamnuska to Loder Mountain. The Eldon Formation is overlain by the Middle Cambrian Pika Formation and the Upper Devonian Fairholme Group. The Fairholme Group is a carbonate platform of massive dolomite, which correlates to oil-producing platform and reef formations of the plains. The Exshaw, Lac des Arcs and associated southwest dipping thrust faults overlap to create a repetition of the erosion-resistant Paleozoic carbonate strata

Table 2.1 Geological formations.

Formation		**Age**	**Lithology**
Recent		Recent	Gravel, sand, silt
Canmore Glaciation		Quaternary	Till, gravel, sand, silt
Bow Valley Glaciation			Till, sand, silt
Pre-Bow Valley		Tertiary-Quarternary	Gravel, sand, cobbles
Brazeau		Upper Cretaceous	Sandstone, mudstone, thin coal beds, marine
Alberta Group	Wapiabi		Dark grey to black shale, marine
	Cardium		Fine grained sandstone, marine
	Blackstone		Dark grey to black mudstone and siltstone (marine)
Blairmore Group		Lower Cretaceous	Sandstone, mudstone, siltstone and conglomerate
Kootenay		Jurassic – Lower Cretaceous	Sandstone, siltstone, mudstone, shale, semi-anthracite coal
Fernie Group			Brown, grey and black shale
Sulphur Mountain – Spray River Group		Triassic	Siltstone, silty dolostone, silty black shale
Rocky Mountain Group		Permian & Pennsylvanian	Hard sandstone
Rundle Group	Etherington	Mississippian	Sandy dolomite, sandy limestone, green shale
	Mount Head		Limestone, dolomite, chert
	Livingstone		Fossiliferous limestone
Exshaw & Banff			Black or grey shale
Palliser		Devonian	Dark grey-black limestone ("Rundlestone")
Alexo			Dolomite, siltstone
Fairholme Group	Southesk		Light grey limestone, dolomite
	Cairn		Dark grey cherty dolomite; stromatoporoids
Lynx Group		Upper Cambrian	Sandy limestone and dolomite
Sullivan			Grey and brown shale
Waterfowl		Middle-Upper Cambrian	Dense limestone, dolomite
Arctomys		Middle Cambrian	Red, green and grey shale
Pika			Limestone, dolomite
Eldon			Limestone, dolomite—hard and massive
Stephen			Grey shale, limestone
Cathedral			Limestone—massive, hard

(Hamilton et al., 1998a; Rutter, 1972; Ollerenshaw,1975)

forming the Fairholme Range that transverses the region from Exshaw to the south end of Barrier Lake.

Within the McConnell thrust sheet, weaker Mesozoic clastic rocks are exposed on either side of the overturned Mount Allan syncline. The syncline occupies the Bow Valley from Canmore to Dead Man's Flats and the Evan-Thomas region of the Kananaskis Valley connected by Wind Valley and Skogan Pass. The clastic deposits that make up the Jurassic Kootenay Group and the lower part of the Blairmore Group occupy the core of the syncline, while the limbs are made of marine shales and sandstones of the Fernie Group. The Kootenay Group, up to 1100 m thick, consists of non-marine sandstones, mudstones and coal seams with abundant conglomerate beds in its upper part. The Kootenay Group in the zone below the Rundle Fault forms the "Cascade Coal Basin" (Dowling, 1907). It hosts as many as 12 seams of low-volatile bituminous and semi-anthracite coal averaging 1.5 m thick or greater. Folding has increased the surface area of coal outcrop. An estimated 180 million tonnes of mineable coal are in place.

Southwest of the Mount Allan syncline, progressively older rocks are exposed toward the west in an overlapping and interfingering fashion. The Rundle and Sulphur Mountain thrust faults run on either side of the Rundle Range, from Canmore to the Eau Claire region of the Kananaskis Valley. The Rundle Range consists of a similar assemblage of Paleozoic carbonate rocks as is seen in the Fairholme Range. The Rundle thrust, trending from Canmore southeast to Peter Lougheed Park sets the Cambrian Pika Formation above the Jurassic Kootenay Group. The Lewis Thrust takes shapes as a series of folds on Mount Kidd and Mount Lougheed and increases in displacement southward, becoming dominant in the Crowsnest Pass area.

Glacial geology and deposition

Glaciers in the Bow Valley originated from higher elevations to the west, moving east down the valley onto the foothills. Coincident glaciers, originating in the peaks surrounding Kananaskis Lakes and to the west, migrated north through the Kananaskis and Spray valleys, sometimes coalescing with Bow Valley ice. When Kananaskis and Bow Valley ice converged, the height of the glaciation in the Kananaskis Valley was controlled by the height of the more dominant Bow Valley glacier. Between glaciations, streams carved trenches into the bottoms of glaciated valleys, depositing alluvium over the valley floor.

Three glacial events of Wisconsin Age (approximately 10,000 years before present) have been recognized. The oldest and unnamed glaciation carved the pre-existing topography; subsequent advances obliterated any deposits it may have left behind. The first recorded deposits come from the Bow Valley advance, which covered the western portion of the Canmore Corridor as far as Exshaw, and the coincident Rocky Creek Glacier, which filled the length of the Kananaskis Valley. The ensuing Canmore advance extended east of the Canmore Corridor into the Morley flats area of the Stoney Reserve (Rutter, 1972). At its Seebe terminus, it coincided with the Mount Wintour advance of the Kananaskis glacier; at its maximum extent, it coincided with the Limestone Mountain advance, which covered the Kananaskis Valley as far as Barrier Lake (Stalker, 1973; Hawes, 1977).

Bow Valley deposits

The western Bow Valley is characterized by a broad valley floor with three levels of benchlands on the lower mountain slopes. The benches on the north side of the valley are well formed and are coarser compared to those to the south. They consist of coarse till, probably deposited as moraine and outwash gravels interbedded with layers of sand. Locally derived shale-rich grey-brown till is found in the Wind Valley region. Strong erosion with shallow till deposition occurs in the central corridor crossing the front ranges. Where the corridor opens onto the foothills, outwash deposits from the Canmore Advance, 15 to 25 m thick, rest on Cretaceous bedrock. The Bow River diverges from the valley fill and is incised into bedrock. The Bow River floodplain contains mainly gravel, including lenses of sand, silt and clay, with aeolian sands along the river margin. Colluvium and rubble drape the lower mountain slopes (Rutter, 1972).

The unconsolidated deposits that fill the bedrock Bow Valley extend to a depth of at least 220 m below the present valley floor. At Dead Man's Flats and Exshaw, 35 m of recent gravel and sand alluvium overlie 150 m of clay till containing minor lenses of silt, sand and gravel, and an additional 35 m of fluvial deposits. The fluvial deposits appear to pre-date the Canmore and Bow Valley advances. In Canmore, sands and gravels extend to a depth of 110 m, followed by 20 m of clay till, 60 m of sand and 20 to 30 m of fluvial cobbles and gravel at the base. The basal fluvial sands and gravels are contained within a channel that appears to be less than a kilometre wide, which existed prior to the Canmore and Bow Valley glaciations.

Alluvial fans, with a high gravel component, create long gentle slopes and encroach on the river in several locations. The communities of Dead Man's Flats, Lac des Arcs and Exshaw, and the Cougar Creek district of Canmore, are built on large alluvial fans.

Kananaskis Valley deposits

In the Kananaskis Valley, surficial deposits are thin or discontinuous in upland areas, increasing up to 60 m in the valleys. No deposits of preglacial age have been recognized.

Late glacial ground moraine is found on the south side of Barrier Lake, on terraces along the valley and in the Marmot Creek basin. Outwash is widespread north and east of Barrier Lake. It is mostly coarse, poorly sorted gravel, plus sand and till. Valley fill includes most of the material in the terraces along the Stony Creek-Lusk Creek valley near Barrier Lake. It is generally thick, up to 65 m in places. It consists of sand, silt and occasionally thin beds of gravel. Glacial stream deposits are found along spillways. As the glacier receded south, up the Kananaskis Valley, it left a mantle of valley train and formed some small eskers and spillways. During the retreat of the Limestone Mountain episode, its terminus stagnated in the Evan-Thomas area, leaving a pitted delta (Hawes, 1977).

Lake deposits are found in the northern end of the valley, but are only exposed in a few places, such as the north end of Barrier Lake. The Bow Valley glaciation blocked the entrance of the Kananaskis Valley below Barrier Lake. At maximum ice height, drainage was diverted east down the Lusk-Stony Creek valley at an elevation of 1525 m. As the Bow Valley Glacier receded, meltwater flowed again down the lower Kananaskis valley, carving out a new base level and impounding a lake at an elevation of 1400 m. Meltwater from the retreating Bow Valley ice flowed through a spillway that hugged the south side of the Bow Valley, building a delta at the mouth of the Kananaskis Valley. It then joined the Kananaskis drainage continuing east. When the Bow Valley ice fully retreated and normal flow resumed, the river cut a trench through the lake deposits (Stalker, 1973).

The Kananaskis River has in places down-cut into the U-shaped valley, but mostly flows in valley fill and has formed a well-developed floodplain in the Evan-Thomas region. Stream deposits are important as alluvium along the floodplain of the Kananaskis River and as alluvial fans along some of the larger tributary streams, particularly Ribbon Creek. Deltaic deposits occur where the Kananaskis River enters Barrier Lake. Alluvial fans are significant as they encroach upon the river, forcing it to move or to cut through the fans. Talus and colluvium occupy small areas beneath steep slopes, accumulating angular material weathered off by frost wedging.

Spray Lakes Valley deposits

Glaciation in the Spray Lakes Valley is not well documented, but during the Rocky Creek Advance, ice from the south end of the Spray Valley area filled the Smith-Dorrien Valley in Peter Lougheed Park to an elevation of 2300 m. The Spray Valley is flanked by blankets of eroded morainal till composed of clay and gravel. In places, particularly at the south and west sides of the reservoir, it is covered by a blanket of colluvial materials (Jackson, 1987). At a number of locations, alluvial fans and terraces composed of gravel encroach on the reservoir. The northern part of the valley is filled with alluvial fan deposits.

The Spray Valley hosts the only remaining glacier in the study area: the Old Goat Glacier on the west side of Spray Lakes Reservoir, which occupies about 0.5 km^2 on Old Goat Mountain.

Aquifers and Groundwater Chemistry

Aquifers

Groundwater is the primary source of potable water in the Bow Valley and Kananaskis regions. It is obtained almost exclusively from surficial sand and gravel aquifers laid down by glacial and fluvial action on the lower mountainsides and in the valley bottoms. (*Surficial* means that the aquifers are found in surficial deposits that were laid by glaciers, even though subsequent deposits may overlie them, making some surficial aquifers very deep.) Bedrock aquifers are accessed only when water from surficial deposits is insufficient or unavailable, mostly in upland areas.

Usually, the aquifers are unconfined, meaning that they are open to the surface and contain the water table. Confined aquifers are typically deeper; one or more layers of low permeability separate them from the surface, and the water level in wells tapped into them will rise above the confining layer.

Surficial aquifers of predominantly gravel and sand, are extensive throughout the valley bottoms and lower mountain slopes. They include moraines, glacial terrace gravels, alluvial fans, fluvial and outwash gravels, and preglacial buried valley deposits. The high porosity and permeability of these deposits and the blanket they form at the surface allows them to intercept large volumes of runoff, which permeate and recharge the aquifers. Surficial aquifers are the main hydrogeological unit to interact with atmospheric and surface waters; their coarse moraines, terrace deposits and alluvial fans form a network that is the primary conduit that transports water from the mountainsides to the outwash plain below, where some of it is discharged to feed areas of springs, seeps, rivers and lakes.

Bedrock in the area, consisting of limestone, dolomite, shale and tight sandstone, tends to have a low permeability, except where it is fractured. Fracturing is related to bedding, weathering and regional tectonics, and is highly scale dependent. Small-scale fracturing may be overprinted by zones of extensive faulting and thrusting, and accompanying weathering and dissolution

Bedrock is exposed at high elevations, but downslope, is overlain by increasingly thick, unconsolidated deposits. The thickest interval of drift identified by drilling occurs at the centre of the Bow Valley, where sand, gravel, silt and clay extend to a depth of 220 m along the axis of a preglacial valley, but is typically less than 50 m elsewhere. The Kananaskis and Spray Lakes valleys have shallower fill, generally extending only to depths in the range of 35 to 65 m. Drift cover thins to less than 12 m at the south ends of the Kananaskis and Spray Lakes valleys and at the eastern end of the Bow Valley (See Chapter 2 for more information about glacial deposits).

Saturation of the drift is highly dependent upon its relative topographic position and on heterogeneities in permeability. In recharge areas, the water table is lowered by downward flow. Colluvium and scree at high elevations, and the benchlands in the Canmore area, often have a low water table caused by partial drainage. Drainage is accentuated where the deposits are consistently coarse and permeable with good vertical exposure and slowed where permeability is heterogeneous or low with limited vertical exposure. Valley bottoms have a consistently high water table, particularly in fluvial sands and gravels adjacent to the Bow and Kananaskis Rivers. The highest groundwater yields are typically found in this region, available at depths less than 25 m.

The main aquifers in the region (Figure 3.1) are: Benchlands, Outwash Plain, Alluvial Fan and Valley, Calgary Buried Valley, and Bedrock.

Benchlands Aquifers

The benchlands are poorly sorted glacial terrace deposits of sand, gravel and clay that flank the western end of the Bow Valley near Canmore. The hamlet of Harvie Heights, Alpine Resort Haven at Dead Man's Flats, the Canmore subdivisions of Silver Tip and Three Sisters, and several quarries on Highway 1A are situated on the benchlands. The coarse, permeable nature of drift along the south-facing benchlands has lowered the water table in many places: Stone Creek Properties' exploratory hole drilled into gravel at the Silver Tip golf course situated on a south-facing benches overlooking Canmore was dry at 85 m. The north-facing benchlands have a reduced permeability and are better at retaining water, but tend to be thin and have poor yields. The Stewart Creek golf

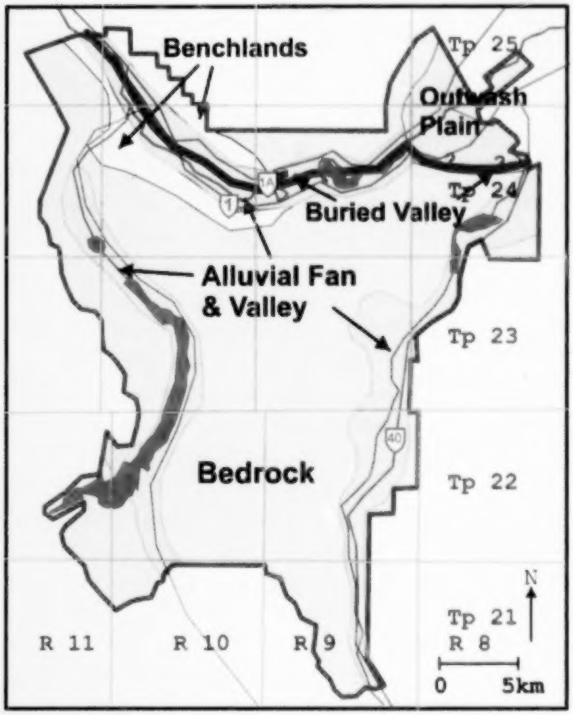


Figure 3.1 Types of aquifers in the study region.

course in the north-facing Three Sisters development found suitable water only after drilling past the surficial deposits, which extended to a depth of 21 m, into bedrock to a depth of 90 m.

Harvie Heights has the highest density of wells in the Bow Valley-Kananaskis region, and is the only community to extensively access groundwater from the benchlands. The surficial geology at Harvie Heights is variable, being a combination of glacial outwash and alluvial fan deposits of gravel, sand, silt and clay in varying proportions. Boundaries between lithologies tend to be indistinct, but aquifers correspond to sandier horizons in the poorly sorted mixture of gravel, sand and clay.

Two aquifer horizons in the hamlet are separated by a clay layer. Some wells completed in the shallower of the two zones experience seasonal fluctuations in water levels, particularly in drought years. Most residents of the upper hamlet access that aquifer, where yields are highly variable. The deeper zone has a hydraulic head close to that of the Bow River, and is more reliable, with yields close to 150 m^3/day. Residents along Bow River Drive and businesses on Harvie Heights Road access that aquifer.

Outwash Plain Aquifer

The outwash plain aquifer covers the Seebe district, including Bow Valley Provincial Park and Yamnuska Natural Area. It consists of unconfined sand, gravels and clays 12 to 20 m thick that rest on Cretaceous shale and sandstone. The aquifer sustains a number of permanent and semi-permanent pothole lakes such as Middle Lake and Chilver Lake that dot the plain.

Groundwater yields are variable and depend on the thickness of the drift and distance from the Bow and Kananaskis rivers. Deposits in the Yamnuska area may be in excess of 35 m at the south-facing foot of the mountain, and thick deposits are also thought to occur in the poorly accessible area below the north face of Barrier Mountain on the opposite side of the valley. The aquifer thins near the Bow and Kananaskis rivers. Below Many Springs, the Bow River, which had meandered on a floodplain of thick alluvial deposits, starts cutting into bedrock. The drift thins to 3 m near Seebe and is drained by the adjacent canyon of the Bow River.

Yields throughout the region are variable, and may be dry or up 560 m^3/day. Because the aquifer is unconfined and is relatively shallow and thin, it is vulnerable to contamination.

Alluvial Fan and Valley Aquifers

Bow River Aquifer

The Bow River Aquifer occupies the floodplain of the Bow River. It is primarily coarse sands, gravels and cobbles of glaciofluvial and fluvial origin. The unconfined aquifer extends only to 40 m from Dead Man's Flats to Exshaw and Kananaskis, but in the Canmore area, it is at least 110 m deep. The water table is typically within a few metres of surface and may fluctuate with the river level. The network of streams that rises out of gravels in the floodplain suggest that the Bow River both contributes to and receives water from the channels through groundwater flow.

Wells drilled into this aquifer are typically shallow because high water tables and high yields rarely warrant drilling beyond 30 m. Early wells in Canmore were commonly sand points driven below the water table. Yields may be in excess of 3300 m^3/day.

The Bow River Aquifer is encroached upon by alluvial fans, the largest being Cougar Creek in Canmore, Pigeon Creek in Dead Man's Flats, Heart

The Bow River floodplain.

Creek in Lac des Arcs and Exshaw Creek in Exshaw. The water levels are similar to that of the Bow River, the flow being received from the flanking mountainsides, but because these areas are relatively elevated, the depth to the water table is greater. Yields are lower than in the floodplain, in the range of 100 to 750 m^3/day. The groundwater type varies at each location, influenced by the source terrain and composition of each alluvial fan.

Kananaskis Valley Aquifer

The Kananaskis Valley Aquifer consists of a combination of glacial, fluvial and alluvial fan deposits on the lower mountain slopes and valley bottom; this unconfined aquifer is up to 50 m thick. Alluvial fans are more prominent than in the Bow Valley, and because the Kananaskis Valley is relatively narrow, fans may cross the valley or coalesce. Fluvial deposits are most prominent where the valley broadens in the Evan-Thomas region. The drift deposits thin at the south end of the valley near Fortress Junction and at the north end of the valley below Barrier Lake.

The Kananaskis Valley Aquifer.

The major facilities at Kananaskis are serviced from centralized wells near the Kananaskis Golf Course. Significant yields are available at shallow depths in the Kananaskis River floodplain, in the range of 200 to 3300 m^3/day.

Spray Lakes Valley Aquifer

Sand and gravel deposits 20 to 60 m thick line the bottom of the Spray Lakes Valley. Drift thickness is greatest in the northern two thirds of the valley. Our drilling program encountered a series of coarsening upwards sequences, indicating that the fill was derived from coalescing alluvial fans. Unlike the Kananaskis and Bow valleys, the Spray Lakes Valley lacks a drainage network capable of laying down fluvial deposits of any appreciable extent. Drift is thin and clay-rich at the south end of the Spray Lakes Valley, with little to no aquifer potential.

Water levels appear to be closely linked to the water level of the Spray Lakes Reservoir and canal system. Draining the reservoir will drain adjacent aquifers. Water levels are more stable and yields are more reliable at the north end of the valley, where the canal system is elevated. Yields are typically up to 200 m^3/day; however a yield in excess of 600 m^3/day was encountered at the Goat Creek day use at the northern tip of the valley.

Calgary Buried Valley Aquifer

Our deep investigative drilling revealed a major sand and gravel aquifer in the Bow Valley. The aquifer was confirmed at drill sites in Canmore, Dead Man's Flats and Exshaw. It is interpreted to be a western extension of the Calgary Buried Valley aquifer, which traverses southern Alberta from the Saskatchewan border west to Calgary. Drilling indicates that the aquifer continues up the Bow Valley toward Banff. Wells greater than 60 m deep at the Banff gate, the Lafarge property in Exshaw, the Graymont Lime property in Kananaskis and at Many Springs suggest that the aquifer is present in these areas. East of Many Springs, the aquifer is uncharted as is diverges from the Bow River. Drilling across the Bow Valley east of Many Springs has ruled out a number of locations and indicates that the aquifer probably follows a route later occupied by a glacial meltwater channel. The meltwater channel hugs the foot of Barrier Mountain, along the south sides of Camp Chief Hector and Bow Valley Provincial Park, continuing east toward Chiniki Lake on the Stoney Indian Reserve. Much of this area is inaccessible to a water well rig.

The buried valley, formed from bedrock, is filled primarily with glacial clay between Dead Man's Flats and the community of Kananaskis. Sands and gravels of the Bow River aquifer extend from surface to depths of 40 m, a clay aquitard extends from 40 m to 190 m and a basal aquifer of sand, gravel and boulders from 190 to 220 m. At Canmore, the clay aquitard is much thinner, covering an interval from 110 m to 132 m. At Many Springs, unconsolidated deposits extend beyond 61 m. The basal gravels at depths greater than 190 m exhibit a fining upwards sequence and appear to be fluvial in nature and predate the Bow Valley and Canmore glacial advances. The portion of the buried valley containing the basal gravels is unconfirmed, but appears to be less than 750 m wide, based on the width of the Bow Valley and several drill sites. The water level rises close to surface at Canmore, Dead Man's Flats and Exshaw, while conditions are flowing at Many Springs, where the water is somewhat diluted by input from the surface aquifer.

Bedrock Aquifers

Bedrock in the region consists of Paleozoic limestone, dolomite and shale, Mesozoic sandstone, shale, coal and conglomerate, and Cretaceous shale and sandstone. Porosity and permeability are poor for Devonian and Mesozoic strata unless enhanced by faulting, fracturing or karst solutioning, and these zones of enhanced permeability are often of limited extent. Yields are typically low, in the order of a few litres per minute or less. Yields from Cretaceous strata are low, but somewhat more reliable.

Few wells are completed in bedrock. Most locations where water is required and can be accessed by a drilling rig are underlain by sufficient water supplies in drift materials. There is rarely a need to go beyond the drift aquifer into the bedrock. Extensive areas are not underlain by a drift aquifer, but these areas are typically inaccessible mountainsides. A few areas lacking drift aquifers access surface water supplies.

The area surrounding Seebe at the eastern end of the Bow Valley is underlain by Cretaceous shales and sandstones of the Alberta Group. The area is disturbed by folding and faulting, but compared to the adjacent front ranges, the strata are relatively flat lying. Yields from sandstones in the Alberta Group tend to be low and inconsistent, although usually present. The deep canyon of the Bow River at Seebe means that adjacent wells must be deep to avoid being drained by the river valley. Seebe currently uses surface water.

Homes in the northern few blocks of Exshaw (Knowlerville) currently use water from Exshaw Creek. One of our investigative wells at Knowlerville encountered yields less than 25 m^3/day of poor-quality water from a contact zone between the Palliser Formation and the Rundle Group at a depth of 37 m. Apart from the contact, the yield from bedrock was negligible.

Our well at Heart Creek on the opposite side of the valley showed yields exceeding 130 m^3/day of good-quality water from fractured limestone at a depth of 30 m. Heart Creek is situated on the Exshaw Thrust Fault, suggesting that positioning of wells along a major fault line can significantly improve yield.

A domestic well in Bighorn Meadows, north of the Bow River and opposite Dead Man's Flats, encountered yields less than 25 m^3/day from dolomite. The well is situated in the vicinity of a large spring, probably of karst origin, that flows from fill beside Highway 1A at a rate of exceeding 1000 m^3/day. However, the well failed to tap into the spring's source.

Drift at the south end of Spray Lakes Reservoir is thin and fairly clay-rich. Three test holes at Buller Day Use were dry. An exploration hole at the Mount Shark parking lot encountered a trickle of water from minor fractures in bedrock. A well completed in limestone at Mount Engadine Lodge yields 10 m^3/day. Improved yields possibly exist along the trace of the Bourgeau Thrust Fault.

In the Kananaskis Valley, three wells explored bedrock near Fortress Junction at the time that Kananaskis Country was being developed. Two were dry, and one had a yield of 25 m^3/day from fractured limestone.

Groundwater chemistry

We compiled a database of 419 groundwater samples for the entire region, including three surface water samples from the Bow River. Samples that were incomplete or of doubtful quality were removed, with 333 samples remaining. We plotted the samples and analyzed them by basic statistical and graphical methods—as a whole group and broken down by region.

Total dissolved solids, major ions and groundwater types

The total dissolved solids concentrations average mean was 290 mg/L and the average mode was 225 mg/L, with the maximum being 1240 and the minimum 70 (Table 3.1). In addition to the buried valley aquifer, three districts had total dissolved solids higher than the average: the region surrounding Seebe, Lac des Arcs and Dead Man's Flats, with Dead Man's Flats significantly higher than average. The Spray Lakes and Upper Kananaskis valleys had the lowest average total dissolved solids for groundwater. Major ions listed in Table 3.2 display a similar trend to total dissolved solids.

Groundwater composition and type (Table 3.3) are influenced by their geological environment and contact time. Limestone and dolomite are contributors of calcium, magnesium and bicarbonate. Anhydrite or gypsum beds, sometimes associated with some carbonate rocks, will contribute sulphate, as will coal. Sodium and chloride tend to be associated with deep basin strata and are uncommon in the mountain environment. With increased contact time and distance from source, groundwater will increase in total dissolved solids content. The dominant ions will shift from calcium, magnesium and bicarbonate toward sulphate, sodium and chloride.

Table 3.1 Total dissolved solids concentrations in groundwater samples.

Location	Average total dissolved solids (mg/L)	Minimum	Maximum	Standard Deviation	No. of Samples
All Samples	290	70	1240	151	333
Canmore	245	70	955	159	68
Dead Man's Flats	660	210	1240	393	13
Exshaw	255	140	380	64	22
Lac des Arcs	390	185	470	68	34
Harvie Heights	255	95	465	60	44
Bow Valley Provincial Park-Seebe	335	190	475	69	25
Many Springs & Buried Valley Aquifer	350	160	475	85	24
Lower Kananaskis Valley	280	170	460	91	9
Upper Kananaskis Valley	225	125	460	69	36
Marmot Creek Basin	270	160	370	70	28
Spray Lakes Valley	190	105	325	58	17
Bow River at Canmore	170	140	205	49	3

Table 3.2 Average concentrations of major ions in groundwater samples (mg/L).

Location	Ca	Mg	Na	HCO$_3$	SO$_4$	Cl	Fe	NO$_3$
All Samples	64	21	10	221	67	7.6	1.3	0.5
Canmore	54	18	14	197	56	2.3	1.2	0.11
Dead Man's Flats	128	40	26	229	275	36	1.0	0.58
Exshaw	63	19	4.5	210	50	4.1	1.0	1.9
Lac des Arcs	86	29	4.2	178	173	6.4	0.3	0.3
Harvie Heights	61	22	8.8	246	23	15	0.7	0.8
Bow Valley Provincial Park-Seebe	70	24	25	345	25	11	1.1	1.1
Many Springs & Buried Valley Aquifer	70	24	3.5	192	100	5.6	0.1	0.09
Lower Kananaskis Valley	64	29	7.9	297	16	4.6	0.8	0.54
Upper Kananaskis Valley	54	17	6.7	207	38	5.9	0.9	0.44
Marmot Creek Basin	53	20	0.7	257	19	7.1	5.5	0.03
Spray Lakes Valley	56	17	1.6	162	47	1.1	0.4	0.22
Bow River at Canmore	43	14	1.6	145	42	1.5	0.08	0.08

Calcium-magnesium-bicarbonate-sulphate type water is characteristic for most of the region. Areas closer to the recharge source, such as the Spray Lakes Valley and Upper Kananaskis Valley tend to have lower than average total dissolved solids. The lower elevation Bow Valley and, in particular, the Calgary Buried Valley aquifer are further from recharge sources and tend to have relatively elevated total dissolved solids. A number of local variations are noted.

Table 3.3 Dominant groundwater types by region.

Location	Primary Groundwater Type	Secondary Groundwater Type
Canmore	Ca-Mg-HCO$_3$-SO$_4$	Ca-Mg-HCO$_3$
Dead Man's Flats	Ca-Mg-HCO$_3$-SO$_4$	Ca-Mg-SO$_4$-HCO$_3$
Exshaw	Ca-Mg-HCO$_3$-SO$_4$	Ca-Mg-HCO$_3$
Lac des Arcs	Ca-Mg-SO$_4$-HCO$_3$	Ca-Mg-HCO$_3$-SO$_4$
Harvie Heights	Ca-Mg-HCO$_3$	None
Bow Valley Provincial Park-Seebe	Ca-Mg-HCO$_3$	None
Many Springs & Buried Valley Aquifer	Ca-Mg-HCO$_3$-SO$_4$	None
Lower Kananaskis Valley	Ca-Mg-HCO$_3$	Ca-Mg-HCO$_3$-SO$_4$
Upper Kananaskis Valley	Ca-Mg-HCO$_3$-SO$_4$	Ca-Mg-HCO$_3$
Marmot Creek Basin	Ca-Mg-HCO$_3$	None
Spray Lakes Valley	Ca-Mg-HCO$_3$-SO$_4$	Ca-Mg-HCO$_3$
Bow River at Canmore	Ca-Mg-HCO$_3$-SO$_4$	None

The Marmot Creek Basin and Harvie Heights are both located on mountainside recharge areas that tend to be flushed of salts, resulting in the calcium-magnesium-bicarbonate groundwater type and low total dissolved solids. The lower Kananaskis Valley and Seebe district are located east of the McConnell Thrust sheet. These regions tend to have a higher total dissolved solids associated with calcium-magnesium-bicarbonate water type. The combination is likely a result of a lack of sulphate in the local Cretaceous strata and a relatively slow groundwater velocity over the relatively flat lying outwash plain.

Exshaw and Lac des Arcs are built on alluvial fans on opposite sides of the Bow River, but have distinct groundwater types. The higher total dissolved solids concentrations and dominance of sulphate over bicarbonate in Lac des Arcs may be attributed to the alluvial fan source terrains. Lac des Arcs is built on the alluvial fan deposited by Heart Creek, which flows over the Palliser Formation, while Exshaw Creek flows across the Etherington Formation. The Etherington Formation consists mainly of dolomite with lesser amounts of limestone and chert. The Palliser Formation is a black limestone, with anhydrite and dolomite beds at its base. Anhydrite would represent a significant source of sulphate. Similarly, high sulphate content is also noted in a well near the Baymag site, west of Exshaw and several springs east of Dead Man's Flats underlain by the Palliser Formation.

Dead Man's Flats has anomalous and fairly inconsistent groundwater chemistry and a relatively low number of samples compared to the rest of the region. Total dissolved solids and sulphate concentrations are higher than anywhere else in the region. A number of springs issuing from deep bedrock sources are found in the area; they may be causing some of the variations. A second factor may be the local geology. Dead Man's Flats is built on the alluvial fan deposited by Pigeon Creek. Pigeon Creek and its tributaries drain the Wind Valley, which is the largest drainage area of any of the local tributaries to the Bow River. The streams flow across Mesozoic strata of the clastic Kootenay, Fernie and Sulphur Mountain Formations, including various sulphate-rich coal-bearing horizons. These may contribute additional ions to the groundwater composition.

Relative composition of groundwater —Piper and Schoeller plots

Water samples from wells and springs in our database were compared on Piper plots (Figure 3.2). Most samples cluster around the composition of Bow River water. The plots show that the relative proportions between calcium and magnesium alone are fairly consistent, around 60% calcium and 40% magnesium. The proportion of sodium is less than 20% compared to calcium plus magnesium. The proportions of anions can be attributed to the dolomite and limestone bedrock that underlies much of the region. For anions, the proportions between bicarbonate and sulphate alone for most samples fall in a range of 40 to 100% bicarbonate, 0 to 40% sulphate. Chloride accounts for less than 10% of the cations versus sulphate plus bicarbonate, with the exception of scattered samples in Canmore, Dead Man's Flats, Seebe, Harvie Heights and Kananaskis. In Harvie Heights, chloride may account for up to 40% of cations. (Appendix, Figure 3.2)

On Schoeller plots (Figure 3.2), most groundwater samples exhibit a similar chemistry to that of the Bow River, although the Bow River water is relatively less concentrated compared to most groundwater samples. This pattern is repeated throughout the Bow Valley-Kananaskis region. Samples from the Spray Lakes Valley, Lac des Arcs and Many Springs show the greatest degree of uniformity amongst themselves. Samples from Dead Man's Flats are the most diverse.

Magnesium, calcium and bicarbonate vary in a small range throughout the region, with deviations occurring at Dead Man's Flats and Tim Horton Ranch in the lower Kananaskis Valley. Variations in sulphate tend to be greatest in Canmore, Dead Man's Flats, Marmot Creek Basin and Spray Lakes Valley; they are likely caused by natural contributions of sulphate from bedrock. At Tim Horton Ranch, deviations from the trend may be tied to the Ranch's unique geological situation above the Cretaceous Blackstone Formation in the easternmost point of the area.

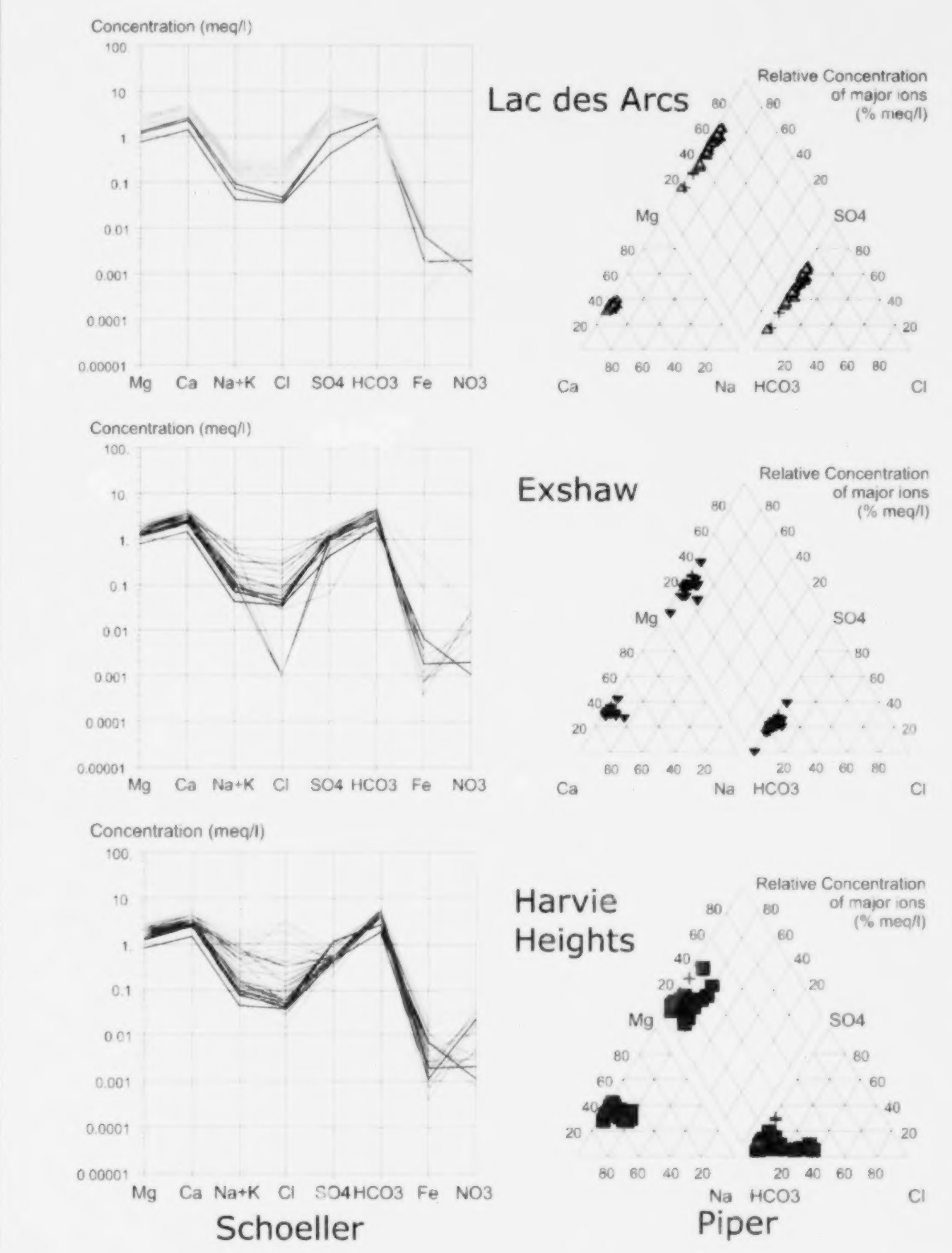


Figure 3.2 Comparison of water samples from Bow Valley communities using Schoeller and Piper plots. Coloured lines and symbols represent groundwater. Black lines and crosses are Bow River water.

A second group of variations consists of elevated sodium and chloride seen in Harvie Heights, Exshaw, Bow Valley Provincial Park and the Kananaskis Valley. The elevated sodium and chloride are likely of anthropogenic origin, derived from septic fields or road salt. Septic fields effective at removing microorganisms are less effective at removing inorganic salts and nitrates. Nitrates occur in varied concentrations throughout the region. Monitoring wells in the vicinity of the Kananaskis water treatment plant site exhibit relatively elevated sodium and chloride. An example of groundwater deterioration was noted at Willow Rock Spring, located below campground facilities in Bow Valley Provincial Park. In 1976, prior to the development of the campground, sampling reported trace sodium and 2 mg/L chloride. Nitrate was not tested. A sample taken from the spring in 1999 reported 49 mg/L sodium, 66 mg/L chloride and 1.5 mg/L nitrate. Sodium, chloride and nitrate from the Calgary Buried Valley aquifer appear at lower concentrations than near-surface aquifers in the region, probably because the aquifer is relatively isolated from the surface.

Drinking water quality

Water quality for the region is good. The *Guidelines for Canadian Drinking Water Quality (2001)* identifies the maximum allowable concentrations (MAC) and aesthetic objectives (AO) for various constituents including the major ions and trace metals tested in this study (Tables 3.4 and 3.5). All major cations and anions were within these objectives for all samples. A small number of samples exceeded the AO of 500 mg/L for total dissolved solids, but these were mostly springs and a scattering of wells in the Dead Man's Flats area. The AO of 500 mg/L is rarely met in most of rural Alberta well water supplies, where 1000 mg/L is commonly considered acceptable.

Iron concentrations exceeding the AO were not uncommon, but were fairly isolated and were specific to individual wells. High iron was typically associated with sporadically used wells with iron casing or where iron-reducing bacteria were present. Springs typically reported low iron concentrations. Fluoride was within MAC of 1.5 mg/L for all samples and was less than 0.7 mg/L for most samples. All samples reported far below the MAC of 45 mg/L for Nitrate, and nearly all samples reported less than 1 mg/L.

Mercury and Arsenic were mostly undetectable and were within the MAC (0.001 mg/L Hg, 0.025 mg/L As) for all samples. Lead was within the MAC of 0.01 mg/L and was near detection limits for nearly all samples. A small number of sites reported anomalous lead, but were related to rarely used hand pumps; none were domestic water supply.

Additional metals tested were Al, Ag, Ba, Be, B, Cd, Cr, Co, Cu, Mn, Mo, Ni, P, Sb, Se, Si, Sr, Th, Sn, Ti, U, V, Zn and Zr. Many are essential nutrients. Few have guidelines associated with them and generally appeared in trace amounts if they were detected at all.

Table 3.4 Major cations, anions and inorganics in drinking water.

Major Cations	**Aesthetic Objective mg/L**	**Effects**
Calcium	200	Hard water; essential nutritional element
Magnesium	150	Hard water; laxative effect; nutritional element
Potassium	-	
Sodium	200	May raise blood pressure
Iron	0.3	poor taste, red staining of laundry and fixtures
Manganese	0.05	poor taste, black staining of laundry and fixtures

Major Anions	**Aesthetic Objective mg/L**	**Effects**
Bicarbonate	700	Hard water
Carbonate	-	
Chloride	250	corrosive
Fluoride	1.5 **maximum**	Essential nutrient; excess can cause dental fluorosis
Hydroxide	-	
Nitrate	45 **maximum***	"blue baby" syndrome in infants
Sulphate	500	Laxative effect

*equivalent to 10 mg/L nitrate-nitrogen

Misc. Inorganics	**Aesthetic Objective**	**Effects**
Turbidity	8 TU	Affects taste, odour
Conductivity	1500 mS/cm	Indicator of Total Dissolved Solids
pH	6.5 to 8.5	<6.5, corrosion of pipes; >8.5. scaling of pipes
Alkalinity	500 mg/L	Scaling of pipes; excessive soap consumption
Hardness	500 mg/L	Scaling of pipes; excessive soap consumption
Total Dissolved Solids	500 mg/L*	Affects taste

*1000 mg/L is widely accepted as the limit in Alberta, 1500 mg/L as the limit in Saskatchewan

Table 3.5 Characteristics of trace elements in water supplies.

Trace Element	Canadian Maximum (mg/L)	Aesthetic Objective (mg/L)	USA – EPA Maximum (mg/L)	Potential Health Effects
Aluminum			0.2	Linked with Alzheimer's disease
Antimony			0.006	Affects blood cholesterol and glucose levels
Arsenic	0.025		0.05	Carcinogenic; damage to skin and circulatory system
Barium	1.0		2.0	Increased blood pressure
Beryllium			0.004	Intestinal lesions
Boron	5			Affects central nervous system
Cadmium	0.005		0.005	Essential nutritional element; excess may cause kidney damage
Chromium	0.05		0.1	Essential nutritional element; excess exposure may lead to allergic dermatitis
Cobalt				In vitamin B_{12}
Copper		1.0	1.3	Essential nutritional element; kidney damage in prolonged excess exposure
Iron		0.3		Essential nutritional element. In large quantities imparts bad taste to water, stains laundry and fixtures.
Lead	0.010		0.015	Cumulative general poison
Lithium				No guideline; readily flushed from body
Manganese		0.05	0.05	Essential nutritional element; In large quantities impart bad taste to water, stains laundry and fixtures.
Mercury	0.001		0.002	Cumulative general poison
Molybdenum				Essential nutritional element
Nickel				Essential nutritional element
Phosphorus				Essential nutritional element
Potassium				Essential nutritional element
Selenium	0.01		0.05	Essential nutritional element. excess causes hair loss, numbness of extremities and circulation problems.
Silicon				Essential nutritional element
Silver			0.10	Non-essential nutritional element; toxic in extreme doses
Sodium		200		Essential nutritional element; large amounts can raise blood pressure.
Strontium				No guideline; rare
Sulphur				No guideline; common in foods
Thallium			0.002	Hair loss, kidney, blood, intestine and liver problems.
Tin				Essential nutritional element
Titanium				No guideline; rare
Uranium	0.1			Kidney damage
Vanadium				Essential nutritional element
Zinc		5.0	5.0	Essential nutritional element; imparts bad taste to water.
Zirconium				No guideline; rare

Springs

Introduction

Areas of natural groundwater discharge or springs are distributed throughout the Bow Valley-Kananaskis region. Springs have played an important role in the cultural development of the region since the discovery of the Banff Hot Springs in 1883. In 1885, Canada's first National Park was established to protect an area of 10 square miles around the springs and expanded to 260 square miles in 1886. In 1902, the federal government extended Banff National Park to cover the entire Bow Valley-Kananaskis region, which remained a part of Banff Park until 1930, when that portion was ceded to provincial jurisdiction.

Springs have been tapped for domestic water supplies at Harvie Heights, Canmore, the community of Kananaskis, the Kananaskis Guest Ranch and the University of Calgary Kananaskis Field Station. The Many Springs complex in Bow Valley Provincial Park was studied extensively around 1980 to determine its suitability as a water supply for a fish hatchery, which was never built. Many Springs and others, such as the Watridge Karst Spring, are now appreciated as unique natural entities.

Springs are areas of concentrated groundwater discharge. Their occurrence is a function of gravity-driven groundwater flow systems interacting with topography and the geological framework. Springs are found in relatively low-lying areas, such as depressions or where there is a break in slope. Discharge may be concentrated by a geological feature, such as a fault fracture, a bedding conduit, or a low-permeability barrier or permeable lens caused by a facies change that distorts the gravity-driven flow field, directing water to the surface.

Contact springs occur at the boundary between two layers of geological materials with contrasting permeabilities, such as sand over clay or sandstone over shale. Karst springs occur in carbonate rocks, where conduits have been enhanced by dissolution of the rock along fractures. Thrust faults provide conduits for deep groundwater to reach the surface. For example, the Banff Hot Springs are situated on the Sulphur Mountain Thrust Fault, and the Canmore Sulphur Spring on the Rundle Fault.

The volume of water a spring discharges depends on the permeability of the source material, the hydraulic gradient and the amount of water available from recharge. In mountainous terrain, surface runoff is highly seasonal. Much of the water entering the Bow, Kananaskis and Spray rivers and their tributaries enters as baseflow or interflow through highly permeable overburden. Seasonal interflow, which is a significant component of drainage in the mountains, can contribute to variations in spring discharge, which may come from shallow and deep sources. Springs on sloping ground tend to have visible points of discharge; however, in rolling or flat-lying terrain, the springs often emerge below a body of surface water. Point-source high flow rates are often associated with fracture porosity. Springs in the Bow Valley-Kananaskis area can vary from small seepages to flows in excess of 1000 L/min.

In the mountains, beaver ponds invariably indicate groundwater discharge. Whereas surface runoff can fluctuate considerably, drying up ponds or flushing out dams, springs provide a consistent source of water. The moist ground surrounding springs also favours the type of woody vegetation that beavers feed on, and the discharge often provides open water throughout the winter. Some of the larger beaver ponds in the region may cover several hectares, and old dams may be overgrown with vegetation and remain long after the beavers have departed. Examples include Steel Brothers Pond, opposite the community of Kananaskis, and the large pond adjacent to the Yamnuska Marl Spring.

Subaqueous springs—those that discharge from beneath a body of water—are visible in winter as open water or ice mounds. They occur at Grotto Pond, Gap Lake and, occasionally, the southwest margins of Lac des Arcs.

Distribution and flow

We documented 75 springs—40 in the Bow Valley, 26 in the Kananaskis Valley and 9 in the Spray Lakes Valley (Figure 4.1). Twenty-seven were originally listed in the GIC database—almost all of them (23) originally identified by the Alberta Research Council as part of their mapping program in the 1970s. We identified 21 during aerial surveys and verified 27 during ground reconnaissance (Table 4.1).

The preponderance of springs along the Bow River corridor is due to its geological and cultural situation. The Bow Valley has a lower elevation, greater topographic relief and more aquifer-forming glacial deposits than do either the Kananaskis or Spray Lakes Valleys; consequently, it probably has better development of groundwater flow systems and greater volumes of discharge. Further, the longer history of settlement and greater access in the Bow Valley has meant that springs were more likely to be visited, documented or used as a water source.

In a region this large, with limited access, the identification and inclusion of springs into a data set becomes a subjective experience. Springs have a large range in flow volumes and may occasionally be seasonal, or influenced by development. Discharge may be diffuse or focused, or may be submerged below lakes, such as Grassi Lakes and Gap Lake, or even beaver ponds. Generally, springs that are identified on the ground have a flow rate of 10 to 50 L/min, are close to a cultural feature and may be ponded. Larger flows become increasingly uncommon, but are more prominent. Sometimes, significantly large volumes of groundwater are discharged, but over a broad-enough areas as to not be recognized as springs.

Flows in the Bow Valley varied from less than 4 L/min for springs in Bow Valley Provincial Park to about 9000 L/min at Many Springs. Relatively high-volume, perennial springs are associated with faulting of limestone and dolomite strata where the Fairholme Range crosses the Bow Valley (e.g., Railside Spring and other unnamed springs at the base of Pigeon and Grotto mountains) or stratigraphic changes, such as Many Springs. In the western part of the valley, springs that

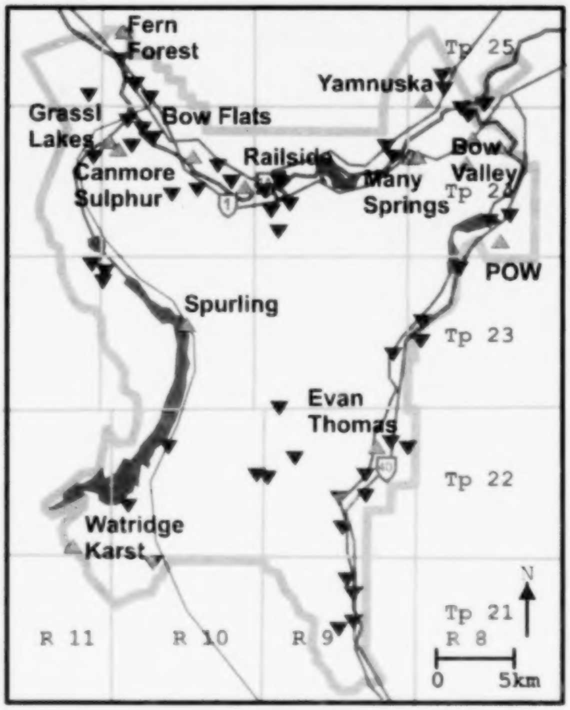


Figure 4.1 Distribution of springs in the Canmore Corridor-Kananaskis region (blue and oranges triangles). Springs named and designated with a reversed orange triangle are described further in this chapter.

Table 4.1 Distribution of springs located in the study area.

Location	Total	Previously Identified in GIC	New Sites (Ground Verified)	Located by Air only (March 2000)
All	75	27	27	21
Bow Valley	40	22	15	3
Kananaskis Valley	26	3	6	17
Spray Lakes Valley	9	2	6	1

commonly issue from glacial materials tend to have smaller discharge rates, or occur as diffuse baseflow. Seepage and baseflow tend to occur in valley bottoms or slopes where the geological material has relatively low matrix porosity.

Fewer springs were observed in the Kananaskis Valley. We noted 13 springs discharging from glacial gravels along the margins of the Kananaskis River in the area between Fortress and Marmot Basin, during our aerial survey of the region in March 2000. Poor access precluded our ground-verifying most of them. Flow was sufficient to create ponding of open water in late winter, close to the river. Other springs observed during the survey were mostly associated with beaver dams at Boundary Ranch, Tim Horton Ranch, and near Mount Lorette Ponds.

Small springs were reported in the Marmot Creek experimental basin as part of that study, but none had flow rates above a few litres per minute (Stevenson, 1967); the highest elevation springs of significant discharge were identified by our survey in the Ribbon Lake cirque at an elevation of 2110 m, 700 m higher than the Kananaskis Valley.

Few springs of any significant discharge were documented in the Spray Lakes Valley. Surface drainage is poorly developed on the valley slopes, and most of the drainage into the valley bottom appears to be groundwater fed, probably occurring as seepage beneath the reservoir. There is a fairly extensive spring and wetland area from Spray Lakes Reservoir to Goat Pond Reservoir. A number of small spring-fed creeks were noted at the south end of the Spray Lakes Reservoir, which is traversed by the Bourgeau Thrust. The Watridge Karst Spring is the largest spring in the valley, with a discharge of about 2400 L/min (page xx).

The types of springs (Table 4.2) vary, and the reasons for their occurrence may not always be obvious, or may be a combination of factors. *Topographic* springs—those occurring in relatively low-lying areas or breaks in slope that cut below the water table, such as Spring Creek—are relatively common throughout the region. *Contact* springs are more prominent along the river in the Bow Valley Provincial Park to Seebe area, where the drift-bedrock contact is relatively shallow. *Stratigraphic* springs are created by permeability variation within strata, which may not be apparent at surface, or as obvious as contact springs. In Alberta, *thrust-fault* springs are generally restricted to the mountains, where faulting and fracturing are common; they are sometimes enhanced by *karst* solutioning of limestone.

Table 4.2 Sample spring types in the study area.

Name	Locality	Type of Spring	Flow Rate (L/min)	TDS	Significance
Many Springs	Bow Valley Prov. Park	stratigraphic	>9000	350	Warm; unique natural area
Willow Rock	Bow Valley Prov. Park	contact	45	675	Supports forest in a grassland environment; changing chemistry
Watridge Karst	Spray Valley Prov. Park	karst	2400	150	Supports old-growth forest
POW	Kananaskis Field Station	topographic	60	350	Historical and cultural
Grassi Lakes	Canmore	topographic	600	250	Recreation
Canmore Sulphur	Canmore	thrust fault	9	1050	Warm sulphur spring
Spring Creek	Canmore	topographic	1500	175	Trout spawning habitat

Water chemistry of springs

Most springs in the region are calcium-magnesium-bicarbonate type. Those with higher discharge tend to be calcium-magnesium-bicarbonate-sulphate type, including Many Springs and springs from the Buried Valley Aquifer (Table 4.3), and a number of springs associated with Devonian carbonate bedrock. The Canmore sulphur spring is an exception to the norm in the area, with calcium-magnesium-sulphate-bicarbonate water.

Total dissolved solids in the springs averaged 325 mg/L. The Bow Valley, excluding Many Springs, showed the greatest variation, from a minimum of 95 mg/L to a high of 1240 mg/L (Table 4.4).

Mineral deposition associated with springs is fairly minor in most of the Bow Valley-Kananaskis region, although spring water is usually more mineralized than surface water. Deposition usually consists of fine precipitates of calcium carbonate in streambeds or as coatings on rocks near the discharge point. For example, fairly heavy deposits of calcareous tufa coat the bedrock in the series of springs below Grassi Lakes. At the Yamnuska Marl Spring, the calcium carbonate replaces moss growing in the fen area, petrifying the material and taking on its form.

Table 4.3 Variation in water characteristics in springs of the study area.

	Flow Rate	Total Dissolved Solids (mg/L)	Chemical Type	Temperature at surface	Maximum Temperature at Depth*
Many Springs	>9000	350	Ca-Mg-HCO$_3$-SO$_4$	7 to 11	13
Buried Valley at Exshaw	>2000	320	Ca-Mg-HCO$_3$-SO$_4$	Unknown	Unknown
Canmore Sulphur Spring	9	900-1100	Ca-Mg-SO$_4$-HCO$_3$	12	28
Three Sisters Sulphur Spring	9	Unknown	Unknown	Unknown	Unknown
Pigeon Mountain Spring	150	1240	Ca-Mg-SO$_4$	7 to 10	Unknown

*(Grasby, 2001)

Table 4.4 Variation in total dissolved solids (mg/L) in springs of the study area.

Location	min TDS mg/L	max TDS mg/L	ave mg/L	no. of samples	min TDS spring	max TDS spring
All Springs	105	1240	325	80	Buller Pond	Pigeon Mountain
Bow Valley, incl. Many Springs	125	1240	385	55	Kananaskis Community	Pigeon Mountain
Kananaskis Valley	170	275	205	10	Barrier	Fortress Junction
Spray Lakes Valley	105	205	165	10	Buller Pond	Goat Pond South
Many Springs	160	475	355	24	Main Pool	9A
Bow Valley, excl. Many Springs	95	1240	410	31	Kananaskis Community	Pigeon Mountain

Sulphur deposition is rare and tends to be fairly minor. It is associated with deeply circulating waters along thrust faults in the presence of sulphur-reducing bacteria. Sulphur deposition was most prevalent at the Canmore Sulphur Spring and at springs near Three Sisters Creek and Pigeon Mountain.

Iron deposition from springs is common in Alberta, but appears to be rare in the mountains. In our survey, few springs were observed that had significant iron precipitation, although iron occasionally appeared as an iridescent film on water, most often in marshy seepage areas. Iron was noticeably lower than in wells, averaging 0.15 mg/L for springs, compared to 1.5 mg/L for all data, suggesting that iron in well water is from anthropogenic sources, probably rusty casing.

Significant springs of the Bow Valley-Kananaskis region

Bow Valley

Many Springs (SW-30-24-08 W5)

The Many Springs complex is a series of springs encircling a fen, located just south of the Bow River at the west end of Bow Valley Provincial Park, where the McConnell Thrust Fault crosses the Bow River. Although thirty springs have been identified in the area, most of the flow comes from three major springs on the south side of the fen, where water gathers into a central stream that flows north to a tributary channel of the Bow River. Minor springs are found along the length of the stream and the tributary channel, which are about 1.5 m above the level of the Bow River.

The springs and surrounding aquifer were extensively investigated between 1979 and 1981 by Monenco Consultants Limited (1980a, 1980b, 1980c) and by Hydrogeological Consultants Limited (1981) for a study commissioned by Alberta Fish and Wildlife, which was investigating possible sites in Kananaskis Country for a fish hatchery. The study involved the drilling of eight monitoring wells and three piezometers, as well as pump testing, temperature and flow rate measurements, and chemistry analyses. Drilling revealed that the springs occur above a northwest-trending bedrock valley several hundred metres wide, filled with sand and gravel deposits in excess of 60 m deep. Northeast of the fen, bedrock is encountered at depths of approximately 18 m.

Traditionally, the source of Many Springs has been ascribed to deeply circulating waters in fractured bed rock associated with the McConnell Thrust Fault, a model similar to that used to describe Banff Hot Springs. However, our investigative drilling between 1999 and 2001 at Canmore, Exshaw and Dead Man's Flats identified a regional buried valley aquifer (Calgary Buried Valley) that must extend beneath Many Springs. The bedrock valley is filled with sand, clay and gravel—to a depth of at least 220 m below the present floor of the Bow Valley—that demonstrates a high yield at Exshaw. This provides a more plausible source of the springs: it is doubtful that fracture porosity alone along the McConnell Thrust Fault could support the magnitude of flow produced at Many Springs, whereas the buried valley easily could do so. Also, water chemistry and flow rates are comparable between Many Springs, situated in the valley bottom, and the buried valley aquifer (Table 4.3), but not between Many Springs and the other warm springs, which are found on mountainsides.

Outlet stream at Many Springs. The McConnell Thrust Fault is visible as the base of the (yellow) cliff.

Beneath Exshaw and Dead Man's Flats, the buried valley aquifer is contained beneath a 150-m thick confining layer of clay. At Many Springs, the confining layer that separates the aquifer from the surface aquifer must be thin, breached or nonexistent to create a conduit for the water to reach the surface. The conduit is probably in some manner related to the McConnell Thrust Fault.

Discharge from the springs was measured using a v-notch weir, which recorded flows as low as 3860 L/min in winter to highs of 8340 L/min in summer. Pump test data revealed that the surrounding aquifer is non-leaky artesian with a Transmissivity of

16,000 m^2/day and Storativity of 0.0001. The long-term yield (Q_{20}) was calculated to be in excess of 9000 L/min (13,000 m^3/day) (Monenco, 1980b), a discharge that is twice as high as might be expected for the basin area. Hydrogeological Consultants (1981) calculated that 40% of the discharge from the Many Springs occurs as underflow to the Bow River via the aquifer.

Groundwater temperatures recorded in springs and wells at Many Springs were mostly between 6.4° and 7.9° C, and were consistently between 7.0° and 7.9° C at depths greater than 20 m (Hydrogeological Consultants Limited, 1981). Grasby and Hutcheon (2001) reported a temperature high of 11.6° C at one spring. Across the Bow River opposite Many Springs, the spring-fed Steel Brothers Pond, a fen below the community of Kananaskis, recorded a temperature near 7° C. Cooler temperatures near 5° C were found to be typical of outlying wells.

"Boiling" sediment caused by concentrated discharge—main pool, Many Springs.

The main discharge from Many Springs is from deep, warm groundwater. It mixes in varying amounts in the aquifer with cooler water recently recharged into near-surface sands and gravels surrounding the aquifer. Temperature variations in samples taken from shallow wells were attributed to the mixing of cooler, near-surface waters with warmer deeply sourced water. Isotopic data (Hydrogeological Consultants Limited 1981; Grasby and Hutcheon, 2001) indicate that the spring water has a meteoric origin, but is heated by deep circulation, which may be related to the McConnell Thrust Fault.

Water samples from the fen area are calcium-magnesium-bicarbonate-sulphate type. Total dissolved solids concentrations average 350 mg/L. Many Springs water samples are moderately high in sodium, chloride and sulphate compared to Bow River water.

All of the original monitoring wells and two of the three piezometers drilled for Alberta Fish and Wildlife remain. One of these wells has been incorporated into the Alberta Environment groundwater monitoring network as Observation Well #364 "Many Springs". It is 40.6 cm in diameter and 29.56 m deep, and has been monitored since 1987. Long-term water levels have remained steady at this well, fluctuating 30 cm on average, with a maximum variation of 80 cm (Appendix F.) The yearly level peaks around the third week of June and then starts a steady decline for the remainder of the year, with the lowest level being recorded at the end of March.

Salts that accumulate on the mud flat of the fen provide a lick for wildlife and raise the pH of the area to favour specialized fen vegetation. Many Springs is home to a variety of orchids, including round-leaved orchid and yellow lady's slipper orchid, and other wetland plants, including elephant head and an insect-eating butterwort. Aquatic isopods, *Salmasellus steganothrix*, are found under the rocks at the springs. These tiny, sightless arthropods are found in only a few other places in western Canada; they live in complete darkness, scavenging on plant debris in a world buffered from the climate by the steady temperature of the springs (Daffern, 1994).

Bow Valley Provincial Park Lake Complex (Secs 21, 22, 27, 28, 29 – 24-08 W5)

Much of Bow Valley Provincial Park is underlain by coarse gravel and sand outwash deposits, 12 to 18 m thick, lying on top of low-permeability shale bedrock. The plain is dotted with a number of permanent lakes with no inlet or outlet, the largest being Chilver Lake. These lakes are closely connected to the groundwater in the surrounding drift, which flows north from Barrier Mountain toward the Bow River. Where the outwash plain approaches the Kananaskis River, springs emerge, and the terrain changes abruptly from dry grassland to dense forest of spruce, poplar, willow and various shade-tolerant, moisture-loving species. In contrast to Many Springs at the western end of Bow Valley Provincial Park, these springs are not mineralized and do not support the same variety of flora and fauna. They do, however, provide critical habitat for salamanders, which benefit from the absence of river-going predators in these isolated water bodies.

Willow Rock Spring, located in the Willow Rock Campground, emerges from gravel at a flow rate of 30 to 45 L/min and a temperature of 2° C. A small pool is formed at the outlet of the spring, which forms

Middle Lake, Bow Valley Provincial Park, is typical of the many spring-fed lakes that have no visible inlet or outlet.

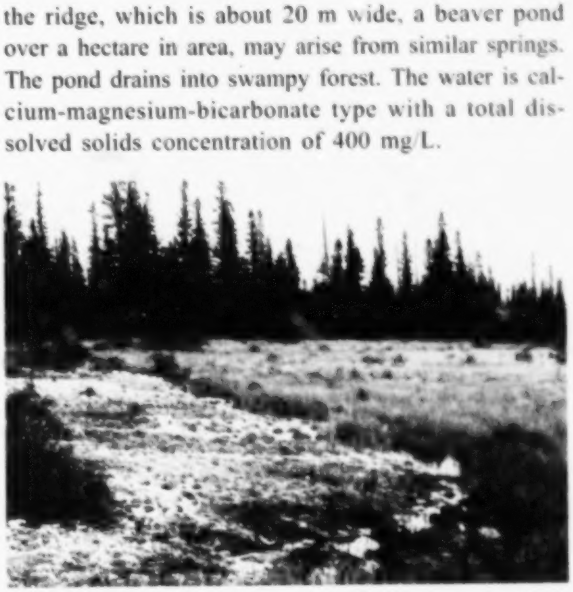
a stream that drains north into the Kananaskis River. Poplar and willow are the dominant vegetation.

Willow Rock water quality appears to have been affected by the adjacent campground development. A 1976 water sample reported a water type of magnesium-calcium bicarbonate with a total dissolved solids concentration of 200 mg/L. In 1999, the water was reported as calcium-magnesium-sodium-bicarbonate; the total dissolved solids concentration had increased to 675 mg/L, and nitrate, although not tested in 1976, was 1.5 mg/L—far above typical background levels of less than 0.3 mg/L. (The background was done by running a histogram on results.)

Illahee Spring rises from a slope of sand and gravel overlying shale bedrock, about 5 m below the plain, immediately north of Rafter Six Ranch. It flows at a rate 30 L/min and has a temperature of 7° C. It forms a stream that drains northeast toward the Kananaskis River. The spring is surrounded by mossy spruce forest, with bush willows around the spring. The water is calcium-magnesium bicarbonate type with total dissolved solids of 350 mg/L.

Yamnuska Marl Spring (NE-06-25-08 W5)

Yamnuska Marl Spring is located in the outwash plain below Mount Yamnuska, discharging onto an area know locally as "The Great Fen". It arises from a ridge in the gravely surficial deposits as a series of small springs that span about 50 m in length, flowing down the embankment into the fen. Calcareous tufa deposits are common amongst the moss. Discharge was difficult to estimate because of a lack of a point source and because the runoff quickly disappears into the moss and sedges of the fen. On the opposite side of the ridge, which is about 20 m wide, a beaver pond over a hectare in area, may arise from similar springs. The pond drains into swampy forest. The water is calcium-magnesium-bicarbonate type with a total dissolved solids concentration of 400 mg/L.



Tufa deposits (lower left) are common among the moss at the Yamnuska Marl Spring.

Railside Spring (NW-18-24-10 W5)

The Railside Spring issues from coarse fill beneath Highway 1A, just below Bighorn Meadows on Grotto Mountain. The spring likely rises from faulting or karst sources in Devonian carbonate bedrock. It occurs below Rat's Nest Cave on Grotto Mountain. It flows year-round at a rate exceeding 1800 L/min, forming a stream that enters the Bow River. Calcium carbonate deposition occurs on rocks lining the streambed, and algae forms thick growths on the stream bottom. Railside is fairly typical of a number of springs that occur where the Fairholme Range crosses the Bow Valley. The Railside spring is calcium-magnesium-bicarbonate-sulphate type water, having a total dissolved solids concentration of 250 mg/L.

Beaver pond adjacent to Yamnuska Marl Spring. Beavers favour springs for siting their dams.

Bow Flats (S ½ 27-24-10 W5)

The Bow Flats is an area of seepage and springs located in the floodplain of the Bow River east of Canmore between Highways 1 and 1A. Groundwater discharges into the northern-most meander of the Bow River, known as Bill Griffiths Creek, which begins as a series of shallow ponds near the junction of Highways 1 and 1A. Rather than having a concentrated discharge point, groundwater flows from seepages along the northern bank of the creek, which joins the Bow River about 4 km downstream. Discharge may be partly underground flow from the adjacent alluvial fan of Cougar Creek and from the extensive deposits of sand and gravel within the Bow River floodplain. Groundwater discharge as baseflow into the stream has been estimated at a rate of approximately 500 to 60,000 L/min per km of streambed, with total discharge of the stream being in the range of 150,000 to 240,000 L/min (Monenco, 1980c).

Water chemistry is similar to that of the Bow River water, suggesting that a significant portion of flow arises from bed flow in the highly permeable Bow River alluvium. Total dissolved solids concentrations are approximately 200 mg/L of calcium-magnesium-bicarbonate-sulphate type water.

Spring Creek in Canmore emerges from the extensive floodplain deposits of the Bow Valley. It is favoured by spawning trout.

Bill Griffiths Creek and nearby stream channels fed by groundwater seepage constitute the most important trout spawning area on the Bow River. The stream temperatures average 5° C in winter, compared to 1.5° C for the Bow River. While the Bow River is often turbid from surface run-off, Bill Griffiths and nearby creeks provide the clear water that is favoured by spawning trout.

Grassi Lakes (SE-25-23-11 W5)

Grassi Lakes are two, small, azure-blue lakes located just below Whiteman's Pass, south of Canmore. While the lakes might appear to be seepage from the Whiteman's Pond reservoir at the top of the Pass, they existed long before the construction of the reservoir in 1948 as part of the Spray Lakes diversion. The lakes are fed from the bottom, which is covered in a thick green layer of algae. The surrounding cliffs are Devonian Cairn Formation, part of the Fairholme Group. The formation is made of cherty dolomite, with abundant foul-smelling organic material, and *Stromatoporoid* beds with *Amphipora* and corals. The cliff on the west side is part of a massive reef complex, with large vugs in the rock where the stromatoporoids have weathered away. The reef complex is popular with rock climbers, who are fond of the pitted but very solid cliff face. The reef is also visited by geologists, who compare the reef to the Devonian oil reservoir rock found on the plains. Ironically, seepage in the area comes from the thinly bedded members of the formation to the east and north of the cliff face.

Lower Grassi Lake, showing the green algae layer.

The trail below Grassi Lakes drops down steep mountain slopes past laminated siltstones and dolomites of the Devonian Alexo Formation, mostly obscured by trees and surficial deposits. Numerous springs issue from the base of the deposits that form a thin cover on the forest floor. The springs are found along a considerable length of trail, which they cross, depositing a layer of tufa where they flow. The magnitude of the combined outflow of the springs exceeds 600 L/min. The streams eventually gather and flow into the Rundle Forebay.

The water is calcium-magnesium-bicarbonate-sulphate type with a total dissolved solids concentration of 250 mg/L.

Springs below Grassi Lakes.

Canmore Sulphur Spring (SE-31-24-10 W5)

The Canmore Sulphur spring is located to the east of the Rundle Forebay in the drainage basin of Canmore Creek. It overlies the Rundle Thrust Fault. The spring emerges from talus, and the fault is not visible at the surface. Where the fault is exposed at the base of Cascade Mountain, Devonian dolomite of the Southesk Formation forms the hanging wall, overlying Triassic shale, siltstone and sandstone of the Spray River Group. There is a metre-wide zone of enhanced permeability along the fault (Grasby, 2001). Discharge from the spring is less than 9 L/min, and the temperature is 6° to 12° C (Van Everdingen, 1972, Grasby, 2001). Grasby and Hutcheon (1999) estimated a maximum temperature of 28° C at the base of circulation in the Rundle Thrust, an elevation of 1200 m.

The smell of H_2S is minor because of a low sulphur concentration (0.4 mg/L) and low discharge rate. The spring flows at a constant rate year-round. It forms a small sulphur-lined pool just below the Rundle Forebay. The upper reaches of much of the Canmore Creek bed exhibit minor tufa and sulphur precipitation and algal growth. The sulphur is thought to originate from coal seams in the Kootenay Formation.

The chemical composition is similar to sulphur springs near Banff. Its total dissolved solids content is 1050 mg/L, significantly higher than most springs in the area, indicating a longer than usual contact time. The water type is calcium-magnesium-sulphate-bicarbonate.

In the 1920s during a mine strike, Lawrence Grassi, a prominent Canmore resident, organized the building of a swimming pool using log cribbing around the spring. It never officially opened to the public, because of concerns of local health officials, who declared it unsanitary. It was condemned and eventually the cribbing rotted away (Appleby, 1975).

Fern Forest, Harvie Heights (NE-18-25-10 W5)

The "Fern Forest" in Harvie Heights is situated in Bow Valley Wildland Park. It is not an actual spring, but an area of diffuse groundwater discharge located on a relatively low-lying area on a glacial bench above Harvie Heights. Groundwater discharge in the form of nutrient-rich seepage has permitted old-growth spruce and fir forest. The moist, heavily shaded forest floor is thickly blanketed with a monoculture of horsetail (*Equisetum*) that has a soft fern-like quality.

The slow seepage of this spring in Harvie Heights results in an old-growth forest of spruce and fir with a carpet of horsetail, otherwise known as the "fern" forest.

Spray Lakes Valley

Spurling Spring (11-22-23-10 W5)

Spurling Spring is located on the east side of the Spray Lakes Reservoir, about 50 m east of the Smith-Dorrien Trail. The spring flows from a mossy bank of coarse glacial deposits, eventually discharging into Spurling Creek, which has a discharge in excess of 9 L/min. The warm (3.5°C) spring water has raised the humidity and moderated the temperatures of the area, creating a favourable microclimate for the thick spruce forest and luxurious growths of moss that follow the channel for a distance below the spring. The total dissolved solids concentration is 240 mg/L, and water is calcium-magnesium-bicarbonate-sulphate type.

Luxurious growths of moss surround the warm water at the outlet of the Spurling Spring in the Spray Lakes Valley.

Watridge Karst Spring (NW-02-22-11 W5)

The Watridge Karst Spring is located on the north slope of Mount Shark at an elevation of 1855 m above sea level. It flows into Watridge creek and then the Spray Lakes Reservoir. Discharge is in excess of 2400 L/min. The water originates from an undetermined karst system on Mount Shark, flowing out of a crevice in the limestone to form a creek that cascades down the mountain. The high humidity and ample moisture supply on this sheltered north-facing slope has created ideal conditions for old-growth spruce forest. The water is calcium-magnesium-bicarbonate-sulphate type with a total dissolved solids concentration of 150 mg/L.

Kananaskis Valley

POW Spring (SE-10-23-08 W5)

The Prisoner of War (POW) spring at the University of Calgary Kananaskis Field Station is used as a water supply for the institution. The spring arises in a hollow on the lower slopes of Mount Baldy. A series of forested mossy ravines collect water that eventually emerges as small streams that collect into a pool. The spring is not significant in terms of discharge, which is around 60 L/min, or other distinguishing characteristics apart from its utilization. During World War II, the field station was a prisoner-of-war camp for German and Canadian internees. They constructed wooden flumes to the two main branches of the spring. The flumes run through a culvert into a treatment house at the base of the slope.

The water is calcium-magnesium-bicarbonate type, with a total dissolved solids concentration of 350 mg/L.

Evan-Thomas Spring (NE-26-22-09 W5)

This substantial spring is located in the Kananaskis River Valley about 0.5 km north of the Evan-Thomas Creek division structure. Flow was estimated at about 7200 L/min in 1979 (Monenco 1980c). The spring appears to be either the re-emergence of Evan-Thomas Creek or groundwater discharge along an old stream channel.

Isotope Analysis

Groundwater sampling program

Between 1999 and 2001, we collected 130 water samples from springs, wells, precipitation and surface water in the Bow Valley-Kananaskis region for isotopic analysis. Analyses were performed by Stephen Taylor at the University of Calgary Stable Isotope Laboratory. Charles Yonge, Ph.D. (Alberta Karst Consulting) and Stephen Grasby, Ph.D. (Geological Survey of Canada) interpreted the isotope results over three field seasons (Yonge, 2000; Yonge, 2001; Grasby, 2002), using different methods of analysis. The following summarizes the content of their three reports.

Theory behind the sampling

Oxygen and Hydrogen, the elements that make up water, have ratios of naturally occurring stable isotopes. ^{1}H accounts for 99.984% of stable hydrogen, whereas ^{2}H (deuterium [D]) accounts for only 0.015%. Similarly, ^{16}O accounts for 99.76%, and ^{18}O 0.10%, of oxygen isotopes. The relative abundances of the isotopes are expressed as the ratio of the heavy isotope to the light isotope (R), with Standard Mean Ocean Water (SMOW) being the common standard. Deviations in the relative abundances of the isotopes are caused by physical or chemical processes that favour one isotope over another. Such deviations are too small to measure accurately, so instead are reported as positive or negative deviations from a standard (or δ) value, where

$$\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000$$

The unit per-mil (‰) represents the deviation from the standard, and R is the isotopic ratio.

As water evaporates from the ocean and moves through the atmosphere, the vapour is depleted of heavier isotopes, which are preferentially removed through condensation and precipitation as the moist air masses move inland from the coast, particularly where the air masses are forced into higher and colder elevations over mountain ranges. (This preferential removal of heavier isotopes is known as the Rayleigh distillation process or "rainout".) Cooler temperatures accentuate fractionation, causing snow to be more depleted in ^{2}H and ^{18}O than rain. Each time the water interacts with its environment or changes phase, it undergoes more fractionation, removing it farther from its original SMOW composition.

When the δ^{2}H (D) and δ^{18}O content of rainwater sampled from around the world are plotted against each other, they form a straight line known as the global meteoric (atmospheric) water line (GMWL), which has an equation of $\delta D = 8\delta^{18}O + 10$, expressed as per mil (‰) (Craig, 1961). Regional meteoric water lines are usually developed for individual regions, in which deviations from the GMWL result from physical or chemical processes other than Raleigh distillation effects; for example, high-temperature processes, such as evaporation or exchange with rock minerals, favour ^{18}O and plot beneath the GMWL. Conversely, samples altered by low-temperature processes, such as condensation, CO_2 exchange, hydration of silicates and H_2S exchange, favour ^{2}H and plot above the GMWL. Thus, snow samples tend to plot above the GMWL, whereas rainfall lies below it if affected by warm evaporative conditions (Yonge and Krause, in prep).

The stable isotopes in precipitation also vary on a regional scale as a function of elevation (Gat, 1980; Rozanski et al., 1993). δD in particular decreases with increasing elevation, resulting from lower temperature, rainout and rainshadow effects.

Groundwater originates as infiltration of precipitation, which travels in the subsurface. A comparison of δD values versus elevation for groundwater sample collection points and the δD versus elevation trend for precipitation may indicate the source elevation and the general extent of the groundwater flow system. In the Rockies, precipitation increases considerably with altitude, but is dispersed over a smaller area than at lower elevations, resulting in a mean elevation that tends toward an average between the sample elevation and maximum elevation.

Isotopic analysis of groundwater in the Bow region

Regional meteoric water line

The regional meteoric line for Calgary (CMWL) (Yonge, unpublished data) is:

$$\delta D = 8.14\ \delta^{18}O + 8$$

The groundwater data for our study area plot close to the CMWL (Figure 5.1) within a normal scatter for global data of 3‰ for ^{18}O and 2‰ for ^{2}H.

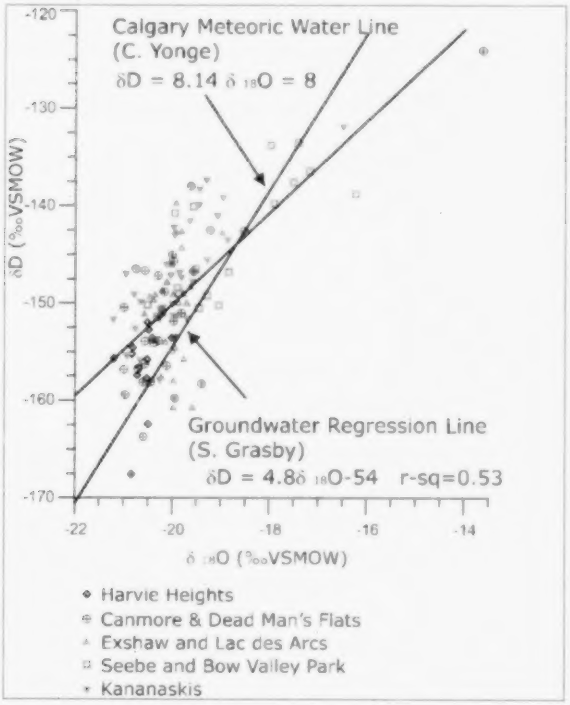


Figure 5.1 Isotope samples at given locations plotted against the Calgary Meteoric Water Line.

A linear regression of the 1999 and 2000 data (excluding two anomalous samples) in the Bow Valley-Kananaskis Country, including precipitation, gave:

$$\delta D = 6.01\ \delta^{18}O - 31.6,\ r^2 = 0.827$$

or

$$\delta D = 6.68\ \delta^{18}O - 17.7,\ r^2 = 0.840$$

Basing the slope on Raleigh distillation, Yonge adjusted the slope of the groundwater data to 8, similar to the CMWL. His final equation for the local meteoric water line was:

$$\delta D = 8.00\ \delta^{18}O + 8.65,\ r^2 = 0.736$$

For all 1999 to 2001 groundwater data, the regression obtained by Grasby was:

$$\delta D = 4.8\ \delta^{18}O - 54,\ r^2 = 0.53$$

(which clusters around the CMWL).

The low slope is similar to one defined for the Bow River (Grasby, 1997); it indicates evaporation. Snow had consistently lower and rainfall consistently higher $\delta^{18}O$ values than groundwater. Groundwater values plotted between those of rainfall and snow, suggesting that both contribute to groundwater recharge.

The Rayleigh distillation process was observed with δD and, to a lesser degree, $\delta^{18}O$ values increasing toward the east in the Bow Valley and toward the North in the Kananaskis Valley. The increasing distance from the Pacific origins of the air masses together with decreasing elevation accounts for this, but the altitudinal effect strongly predominates over rainout.

Grasby proposed interpreting the groundwater data in terms of separate best-fit lines for precipitation and for groundwater. While precipitation may be fresh, the waters that recharge groundwater may have been altered by the evapotranspiration of precipitation and the evaporation or sublimation of snow packs, which would cause the best-fit line to have a lower slope than the CMWL.

Altitudinal variations in δ values

Samples came primarily from wells and springs, although a limited number of snow, rainfall and surface water samples were collected. Most of the groundwater samples were collected from the valley bottoms, which represent areas of regional discharge. A significant number of precipitation samples collected at a variety of locations and altitudes throughout the year are required to effectively determine the δD relationships to altitude specific to the Bow Valley-Kananaskis region; however, weather, timing and access considerations prevented collection of such a suite during the course of our study. The limited number and variety of rain, snow and surface water samples that were collected were insufficient to correlate to the groundwater samples.

In the absence of sufficient local precipitation data, Yonge generated a model relationship based on studies by Yurtsever and Gat (1981), Razanski and Sonntag (1982), and Lawrence et al. (1982). The intercept was determined in accordance with the Pacific Coast at the study latitude (Yonge et al., 1989) and the gradient of -25 m ‰ for δD used for other locations in western North America (Rozanski et al., 1993; Sharp et al., 1960; Rozanski and Sonntag, 1982). The δD demonstrates a decrease with increasing elevation caused by the temperature effect and adiabatic lapse rate.

Yonge noted that the model line (Figure 5.2) falls on the upper edge of the data collection as expected, indicating that the groundwater was derived from higher source elevations. The separation of data from the model line for Kananaskis Country is smaller and more scattered than the consistent linear trend formed by samples from the Bow Valley. The samples from the Kananaskis region form a slope that is lower, but mostly parallel to, the model slope, while the Bow Valley sample group has an almost flat slope. Kananaskis sites appear to receive their water close to their actual altitude.

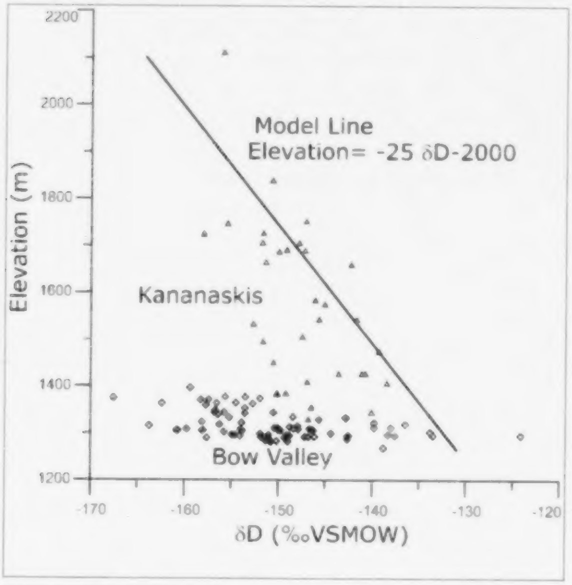


Figure 5.2 Model line for the study area vs. elevation.

Meteoric processes were the dominant factor determining δD and $\delta^{18}O$ values in the region. Samples from the Bow Valley are recharged from the adjacent Rundle and Fairholme Ranges. The δD versus elevation relationship for samples from the Bow Valley slopes gradually eastward, reflecting the progressive lowering of the basin elevation toward the east.

Samples collected in the Canmore area indicate a mean groundwater elevation of around 1800 m. Springs at the base of Grotto Mountain near the Gap had a calculated mean close to 1730 m. The water from Many Springs in Bow Valley Provincial Park is isotopically depleted compared to other sites in the vicinity, indicating a more distant source. It plots close to samples collected in the vicinity of Canmore and has a calculated elevation of 1760 m. Sulphur spring samples from Mt. Rundle and Mount Lawrence Grassi near Canmore suggest a mean groundwater source elevation of around 1970 m.

A plot illustrating D-excess (Figure 5.3) indicates that samples from higher elevations conform more to the GMWL at a D-excess of 10. This may suggest that modifying processes have influenced samples less at higher elevations, where they are closer to source elevations, but further data are needed to test this hypothesis.

Grasby did not develop a model line for the region, noting an anomalous δD versus elevation profile for snow pack in Banff from recent unpublished work (Grasby and Lepitzki, in review). Until sufficient detailed sampling of precipitation at various elevations is done throughout the region to establish a local profile, he doubted that a meaningful relationship could be proposed at this time.

Grasby noted that the range in δD values along the valley bottom (1300 to 1400 m elevation) is in the range of -120 to -170‰, which exceeds the range of values for higher elevations (1400 to 1900 m) of -140 to -160‰. Since the range of δD values for the valley bottom was

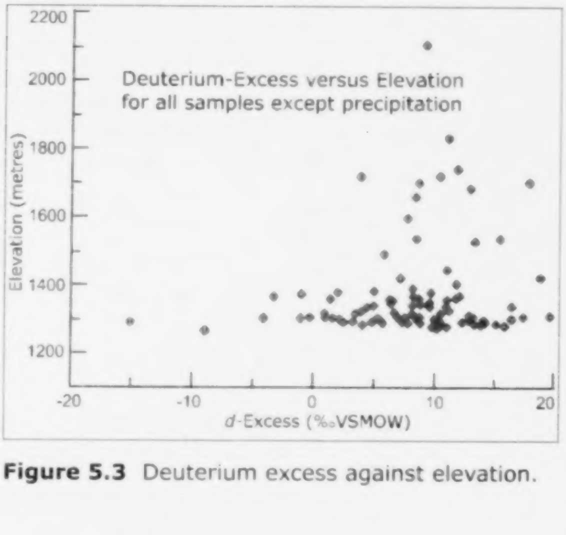


Figure 5.3 Deuterium excess against elevation.

greater than the range of the elevation profile, no statistically meaningful relationship could be extracted on a broad scale amongst the samples themselves.

Spatial variations in δ values

δ values, particularly for deuterium, may develop spatial relationships caused by the dominance and direction of a particular weather pattern. Two weather systems affect the region. Dominant westerlies originating from the Pacific Ocean provide winter snowfall at higher altitudes. Weaker easterlies from the Gulf of Mexico provide summer rainfall, mostly at lower elevations, thereby diminishing the rainshadow on the eastern slopes that is effect seen in winter (Yonge, 1989; Grasby, 1997). As the easterlies are derived from warmer latitudes, they tend to have a higher bulk stable isotope composition at their point of origin than the westerlies. Bulk stable isotope compositions decrease progressively inland as a result of fractionation, primarily from rainout and orographic effects.

Yonge noted that the dominant weather systems track from southwest to northeast over the Rocky Mountains, preferentially moving up valleys that are somewhat aligned to regional systems. Depletions caused by falling elevations and rainout will occur along such valleys. The overall slope δD/distance eastward is about 0.45‰ per km or 0.32‰ for SW to NE. This is twice as high as reported gradients for the front ranges and foothills (Yonge et al., 1989). The higher gradient is caused by the dominating effect of dropping altitude of sites eastward more than that of rainout. Positive slopes of δD /distance in the Alberta Rockies have been interpreted as being caused by the mixing of Pacific air masses with continental weather systems originating from the east (Yonge and Krause, in prep).

In both the Kananaskis and Bow Valleys, a linear correlation was observable, the Bow Valley having less scatter than Kananaskis. The best correlation coefficients were obtained in the W-E direction for the Bow Valley (r^2=0.52) and S-N for the Kananaskis Valley (r^2= 0.57).

Grasby plotted the δD values by easting and northing. He noted a progressive increase in δD from west to east (Figure 5.4), but he interpreted no correlation as being significant in the north-south direction. The Bow Valley exhibited a trend of 0.5‰/km, and the Kananaskis region 0.3‰/km, with correlation coefficients of 0.43 and 0.30, respectively. Variation often occurred amongst samples that were collected from the same vicinity, such as Harvie Heights, indicating other factors at play, such as seasonal differences.

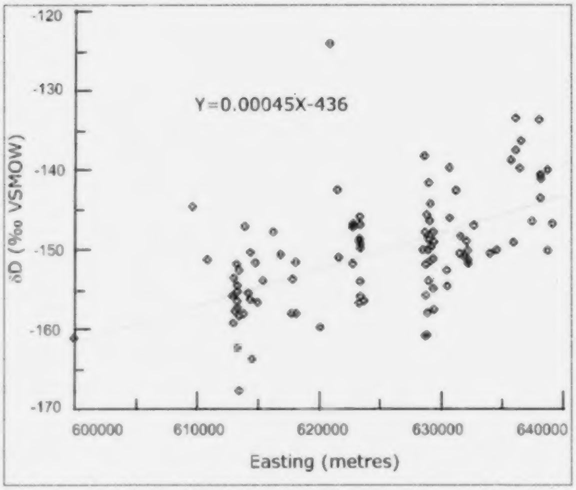


Figure 5.4 East-west trend in δD values (Bow Valley).

Seasonal changes in δD

Correlations were not very clear, but on average, the snowmelt expresses itself in the aquifers at the end of April. Summer precipitation with the highest dD values is found around the end of September.

General sample characteristics by location

Within individual regions, the groundwater data were fairly homogenous, and meaningful differences were not seen between the data. Some general characteristics were noted:

Harvie Heights and Canmore groundwater was recharged from the adjacent mountain range.

At Lac des Arcs, Exshaw and Dead Man's Flats, groundwater was recharged from the adjacent mountain ranges, rather than Bow River Sources.

Most springs in Bow Valley Provincial Park were derived from local sources, except for Many Springs, which had a higher, more distant source.

Most springs and wells in Kananaskis indicated distant sources, while in the Spray Valley, the source elevation was relatively close to collection level.

An anomalous sample with D-excess from the Old Camp spring at the base of the south-facing gravel benchlands appeared to be modified by evaporation.

An anomalous sample from a spring below the Kananaskis Dam at Seebe was likely affected by infiltrating water from the Bow River.

Conclusions

Samples clustered around the local meteoric water line, with a low slope suggesting the samples had been affected by evapotranspiration. The elevation of groundwater recharge is the strongest influence on isotopic values.

An east-west spatial variability is related to the movement of weather systems down the mountain valley.

Recharge to the groundwater systems occurs as precipitation on the adjacent mountain ranges. Occasionally, deep springs, such as Many Springs or the Canmore sulphur spring, have more distant sources. Interpretation of the recharge elevation was hampered by the lack of a diagnostic suite of precipitation samples.

Groundwater as an Ecological Resource

Groundwater interactions with the environment

The Bow Valley-Kananaskis region is recognized primarily for its diversity of natural environments within a limited geographical area; that diversity is created by extreme variations in topography, climate and weather (including Chinook winds), altitude, solar radiation, slope, aspect and groundwater. Residents, visitors, businesses, institutions and industries share this rugged terrain and variable climate with myriad wildlife and plant communities.

Groundwater, as an essential component of the hydrologic cycle, sustains the multitude of uses in the area. Similar to surface flow, groundwater flow divides at mountain ridges and converges at valley bottoms. In the process, it modifies the extremes of climate and imprints a variety of moisture and nutrient regimes on the landscape, which, in turn, support a variety of vegetation zones and faunal habitats.

Changes to groundwater flow systems may occur through various land uses that alter land surface characteristics. Mining may change flow boundary conditions by altering surface topography. Groundwater withdrawals will alter adjacent flow fields. Vegetative removal, such as forestry or urbanization in uplands may change recharge characteristics, while removal of phreatophytic vegetation in the discharge zone may reduce evapotranspiration, or alter the protective influence of the riparian zone on river margins.

As it flows through the subsurface, groundwater interacts with its physical, chemical, biological and hydrologic surroundings. It loses water to the atmosphere through capillary action, transpiration by plants and evaporation near the land surface, and it gains water through infiltration of precipitation and runoff. As well, it gains and loses as it exchanges water with streams, lakes or wetlands along the way.

In recharge areas, where the water table is low, descending cold waters depress thermal gradients, increasing temperature and moisture stresses on vegetation. Conversely, in discharge areas, a high water table and ascending warm waters moderate stresses on root zones, and open water occurs on otherwise frozen streams, lakes and ponds.

Salts and nutrients are leached from high elevations and transported by groundwater to lowlands, where they are concentrated near springs and seeps. The greatest benefit occurs in otherwise deficient, coarse-grained media, where the constant supply of moisture, nutrients and trace elements enhances the growth of vegetation and the development of soil profiles (Klijn and Witte, 1999; Tóth, 1966). In particular, phosphorus and nitrogen enhance plant growth, while precipitation of salts favours certain plant species and harms others.

Certain plant species or communities depend on the specialized habitats produced and maintained by groundwater flow (Klijn and Witte, 1999). Within a climate zone, most plants can tolerate a range of moisture, nutrient and temperature conditions; however how a plant fares at a site depends on its particular tolerances, and competition from more aggressive species. Groundwater modifies the physical and chemical environment and influences the vegetative associations in recharge, discharge and flow-through areas; it is the associations of species, more than any individual species that reflects a groundwater regime (Tóth, 1972, Leskiw, 1971).

Land mammals depend on the distribution of vegetative cover for shelter from the elements and to hide from predators. Aquatic fauna dependent on dissolved nutrients, organic matter, moderated temperatures and terrestrial fauna seeking particular habitats as a food source or for cover will colonize or habituate areas where these are readily available. Some areas may be seasonally significant or even critical for migratory species.

Ecoregions

Ecoregions are areas characterized by distinctive regional climate, expressed by repeated vegetation associations. There are three ecoregions within the Bow Valley-Kananaskis area: Montane, Subalpine and Alpine.

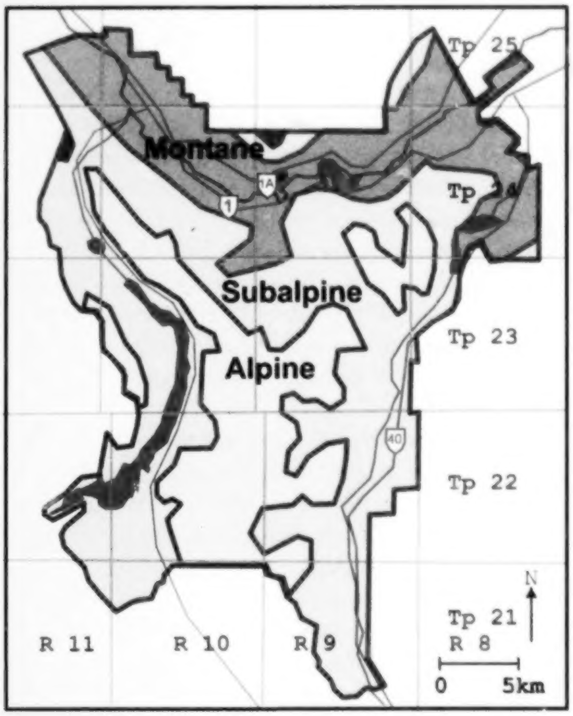


Figure 6.1 The three ecoregions of the study area.

Montane

Unlike other ecoregions of Alberta, which form major contiguous landscapes, the Montane occurs as enclaves in the valley bottoms and lower mountain slopes of major mountain passes that allow warm Pacific air to descend and flow through the valleys. Wedged between the Subalpine and Alpine, it covers less than 1% of Alberta. In the Bow Valley-Kananaskis area, this ecoregion is primarily found in the east-west trending Bow Valley, with minor extensions into those parts of Wind Valley and Kananaskis Valley that abut the Bow (Figure 6.1).

The Montane is the warmest and driest ecoregion in the mountains. In winter, its valleys are buffered from the effects of arctic continental air masses, and are periodically warmed by Chinook winds. Annual precipitation varies from 400 to 550 mm, with potential evapotranspiration in the same range, causing the region to be marginally semiarid. Much of the moisture in this region is redirected through streams and groundwater that originate from precipitation in the Alpine and Subalpine zones of the watersheds.

The warm and dry climate creates the most ecologically diverse ecoregion in the Rocky Mountains (Pacas et al., 1996), comprising grasslands, wetlands of riparian vegetation and open forests of aspen, lodgepole pine, white spruce and Douglas fir (a signature species found only in the Montane, in Alberta). In conjunction with the streams, lakes and alluvial fans, the rich diversity of plant assemblages provides prime habitat for a wide variety of birds, carnivores, small mammals, ungulates and amphibians (Holland and Coen, 1982).

Subalpine and Alpine

The Subalpine ecoregion occupies the mid to upper mountain slopes of the Bow Valley and lower Kananaskis Valley and the valley and slopes of the upper Kananaskis Valley and the Spray Lakes Valley; it is characterized by lodgepole pine and occasionally aspen in dry or burned areas, and closed mossy forests of Engelmann spruce and subalpine fir where conditions are moist and cool. The Alpine ecoregion occurs above the Subalpine where the forest thins, giving way to barren rock, small shrubs, grasses and other forbs (Strong, 1992).

Both the Subalpine and Alpine are relatively wet regions: they have limited evapotranspiration and receive at least 650 mm, and sometimes more than 1150 mm, of precipitation. Together, they are the primary watersheds for the prairies (Alberta Forestry Lands & Wildlife, 1988).

The harsh climate of the Subalpine and Alpine limits inherent diversity, particularly in the alpine zone; however, the proximity to the Montane enhances wildlife diversity in both zones through seasonal migration. The Alpine also offers unique habitat to truly mountain species, such as bighorn sheep, mountain goats and various small mammals, such as pikas and hoary marmots.

Effects of groundwater flow on the distribution of flora and fauna

Although precipitation/evapotranspiration balances show the Montane to be relatively dry and the Subalpine and Alpine to be relatively wet, the Montane landscape is effectively moist and nutrient rich, whereas the two upper ecoregions are drier and more nutrient poor. This apparent paradox is entirely due to groundwater flow from the coarse-grained and steep recharge areas of the higher elevations to the shallower discharge areas along the lower slopes and in the valley bottoms.

The Montane benefits substantially from redistribution of water from the more elevated ecoregions. Being primarily a discharge zone, it garners a positive soil moisture balance and a notable increase in water availability, expressed in such features as alluvial fans, springs, streams and lakes. And, because the groundwater flow typically has a long residence time, a high concentration of dissolved matter brings nutrients with the flow. These moist, nutrient-rich discharge areas contrast with the dry, nutrient-poor recharge areas that remain in other parts of the Montane, augmented by the warmer climate, to create a high degree of biodiversity.

To a lesser extent, the Subalpine ecoregion benefits from groundwater redistribution, especially in the Spray Lakes and upper Kananaskis valleys, where it occupies the discharge areas. However, the Subalpine does not have the warmer, drier climate of the Montane and the groundwater flow distance is not usually as great, so its benefits are not as prominent and are often more localized.

The Montane and Subalpine ecoregions have characteristic assemblages of vegetation based on the enhanced moisture and nutrient availability (Archibald et al., 1996). A competitive advantage is gained by certain species in each environment, based on tolerance of site conditions and relative vigour. Various fauna are also attracted to these areas for the habitat they provide. Conversely, the Alpine ecoregion tends to be too harsh for definitive vegetative assemblages to develop.

Montane vegetation varies locally from grassland, parkland, open and closed forest, to wetlands. Forested areas consist of Douglas fir and lodgepole pine and/or aspen stands with secondary succession to white spruce (Strong, 1992). Understory vegetation is diverse, but includes Canada buffaloberry, bearberry and snow berry. Much of the vegetative renewal is dependent on various forms of disturbance (Green et al., 1996), including those caused by groundwater flow. For example, willow thickets and sedges are common in wetland areas.

The higher relative elevation of the Subalpine ecoregion and the smaller scale of groundwater flow subdues many of the field manifestations that are prominent in the Montane. Cooler temperatures restrict the growth of heat-dependent species, but also create a hospitable environment for a few cool-temperature species generally not found at lower elevations, such as white flowered rhododendron, false azalea, grouseberry and mountain heather. Elevation is a significant factor in plant distribution. Lower elevations of the Subalpine region are characteristically closed forests of lodgepole pine, Engelmann spruce and subalpine fir. At higher elevations, the forest canopy is more open with subalpine larch and whitebark pine. Grasslands are also common on dry, steep south- and west-facing slopes, such as those on Pigeon Mountain in Wind Valley.

Animals depend on their habitat to provide food, thermal cover, hiding cover and escape routes. Vegetative assemblages that provide good sources of food for some species may provide poor cover or escape routes from predators. The effect is most pronounced in the Montane ecoregion. Good thermal cover is provided by mature Douglas fir, lodgepole pine, spruce or fir forest, but these areas are often poor forage. Adjoining wetlands, grasslands, shrub lands, or deciduous forest such as aspen provide poor thermal cover, but are better forage areas for most species (Westworth et al., 1984). Prime habitat occurs where there are significant edges, patchworks of different vegetation types (O'Leary, 1988). The redistribution of moisture, heat and nutrients though gravity-driven flow systems in regions of varying topography, such as most of the Montane and some of the subalpine, creates and maintains variable site conditions necessary for this patchwork to exist.

Recharge areas

In the Montane, recharge occurs on regional or local topographic highs such as benchlands or drumlins, and is enhanced where coarse substrates allow rapid infiltration to a deep water table. Nutrients are mobilized and leached by percolating groundwater. As soil moisture is dry to slightly moist, drought-tolerant species have a competitive advantage.

In the Montane, species such as rough fescue, hairy wild rye, bearberry, juniper, Douglas fir or lodgepole pine occupy recharge areas. On dry, nutrient-poor sites, Douglas fir forms an open tree canopy with a well-developed grass layer—typically rough fescue, and bearberry on exposed south-facing mountainsides where the water table is deep. In the Bow Valley, this association is found on the upper slopes of south-facing benchlands through much of the western half of the corridor and near Exshaw and Wind Valley.

On slightly moist, nutrient-poor sites, lodgepole pine, aspen and white spruce form pure and mixed stands, with a ground cover of juniper, bearberry and grasses and occasional shrubs or forbs. There is a slow succession toward white spruce. Trees are scattered between grasslands in drier sites and the canopy is closed where moisture conditions are better. Shrubs and forbs are sparse in wooded areas. This association is typical of portions of the benchlands and of the elevated outwash plain in the east.

Depletion of soil moisture and nutrients though groundwater recharge helps to maintain the grassland and open woodland areas. Where moisture conditions are better, and without renewal through periodic drought, fire, and grazing, Douglas fir, lodgepole pine and aspen give way to spruce. Spruce forests allow little light penetration, reducing the understory of shrubs and grasses to mosses. Berry production plummets, and fewer herbs and shrubs are available for grazers/browsers (Figure 6.2).

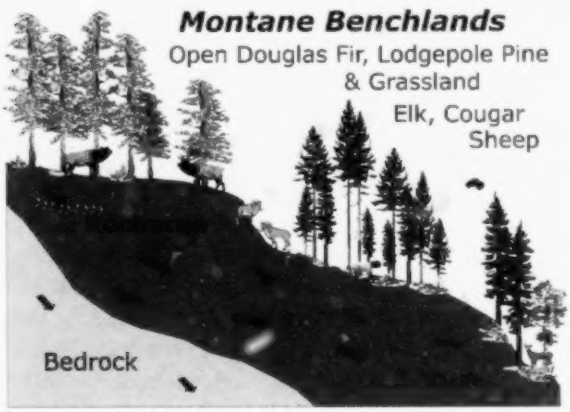


Figure 6.2 Generalized plant and animal assemblages for a groundwater recharge zone, Montane ecoregion.

In the Subalpine, lichens, juniper, bearberry, hairy wild rye and lodgepole pine are characteristic species of nutrient deficient-recharge areas. The largest area of this type is found in Wind Valley, on south-facing slopes of Pigeon Mountain (Figure 6.3).

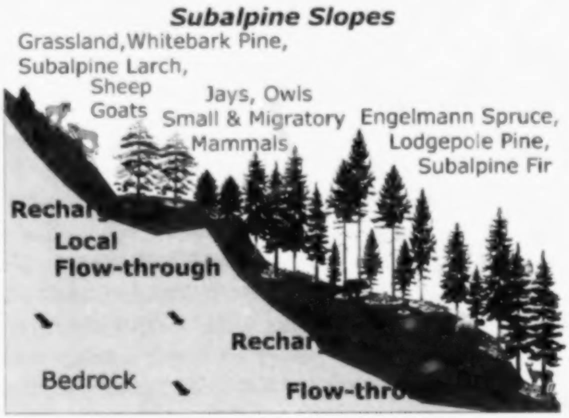


Figure 6.3 Generalized plant and animal assemblages for a groundwater recharge and lateral flow area, Subalpine ecoregion.

The grasslands and open woodland of Montane and Subalpine recharge areas provide habitat for a wide variety of animals, including elk, mountain sheep, deer, cougar, coyotes, birds, small mammals and rodents. Elk and bighorn sheep, in particular, favour these environments in winter.

Elk are generalist feeders of grasses, forbs, sedges and shrubs in winter and deciduous trees in summer. Since deep snow prevents grazing, elk favour dry open areas, exposed to sun and Chinook winds for fall and winter range (Skolvin, 1982). A population of 350 elk live in the Montane of the Canmore Corridor: 100 in the eastern outwash plain, 150 in Wind Valley/Pigeon Mountain and 100 interspersed through the benchlands (Alberta Forestry Lands & Wildlife, 1990).

Bighorn sheep favour the same wind-blown feeding areas as elk; however they also require cliffs and steep slopes to escape predators. Dry, barren slopes in recharge areas tend to have a greater slope because of the low degree of saturation, so they provide the right juxtaposition of feeding and escape habitat. As sheep are well adapted to higher elevations, they occupy both the Montane and Subalpine regions. A population of 300 bighorn sheep inhabits the Montane of the Bow Corridor, half on dry, south-facing slopes, particularly in the central corridor, and the other half on Douglas fir forests and grasslands on south-facing slopes of Wind Valley. Prime wintering habitat is also found on Mt. Allan and along other wind-blown, steep slopes in the Subalpine.

The healthy ungulate population of the recharge areas, particularly the Wind Valley region, helps to support a variety of carnivores including grizzly and black bears, wolverine, wolf, lynx, fox, coyote and cougar (University of Calgary, 1994; Alberta Environmental Protection, 1997b).

Flow-through areas

Dominantly lateral groundwater flow results in moist sites with a moderately enriched assemblage of nutrients, typical of middle to lower topography on gentle slopes. Transient groundwater recharge or seepage may occur after heavy rain or during spring runoff. Humus is well developed.

In the Montane region, aspen are typical of moderately moist, well-drained sites, often interspersed with white spruce. Lodgepole pine, Douglas fir and white spruce form pure and mixed stands on drier sites, while aspen and white spruce favour areas where moisture and nutrient conditions are better. This site supports a wide variety of plant communities including creeping mahonia, green alder, snowberry, pine grass and Schreber's moss on drier sites and dense shrubby understories of dogwood, low-bush cranberry, saskatoon and prickly rose on moist sites. Succession is toward white spruce. Disturbance can cause a rapid increase in shrub and forb cover, and favours primarily aspen, as well as lodgepole pine (Figure 6.4).

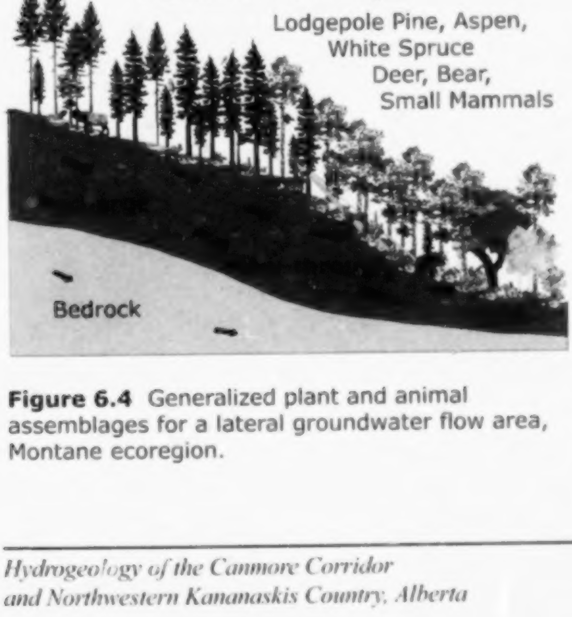


Figure 6.4 Generalized plant and animal assemblages for a lateral groundwater flow area, Montane ecoregion.

The woodlands of Montane flow-through areas provide biologically diverse habitat for Columbian ground squirrel, red squirrel, meadow vole, ruffed grouse, warbling vireo, downy woodpecker, elk, mule, and white-tailed deer and numerous birds (Holland and Coen, 1983), as aspen woodland is second only to riparian forest in terms of overall diversity. Aspen and deciduous shrubs are a favoured food of browsing deer and elk, and beaver. Buffalo berries grow best under the open canopy of scattered deciduous woodland, where they provide a high-energy seasonal food source critical to species like black bears that are trying to build up energy stores for reproduction and hibernation.

Flow-through conditions are typical of much of Yamnuska Natural Area, one of the most ecologically diverse areas of Alberta. Mixed woodland is interspersed with grasslands and, in some places, small lakes and ponds, fens and beaver ponds. It is home to an unusually wide range of plant species, some rare or uncommon. There are 362 documented vascular plants: 9 are rare, and 11 uncommon. It hosts over 180 species of butterflies and moths. There are 14 distinct vegetation communities. The area is spring calving range for elk, which migrate from their grassland wintering grounds to wooded areas that provide cover for their young (Alberta Environment, 1999).

In the Subalpine, flow-through areas of scattered subalpine larch, subalpine fir, heather and grouseberry occur in moist, nutrient-poor sites, generally in cirque valleys near timberline. Such sites are small, rare and scattered in the Bow Valley-Kananaskis region. The valley of the ten peaks (Larch Valley) near Lake Louise in Banff National Park is a classic example on a larger scale. More typical mid-slope vegetation are lodgepole pine on disturbed or burnt sites succeeded by Engelmann spruce and subalpine fir. Other species include grouseberry, false azalea, thimbleberry, green alder and pine grass. The generally closed forests in the subalpine zone are less conducive to wildlife, but are home to such forest species as lynx, snowshoe hare, Canada jay and small mammals (Figure 6.3).

Discharge areas

Regions of groundwater discharge occur in relative topographic lows, particularly in valley bottoms, near rivers and streams, and ponds. Groundwater seepage and high water tables are characteristic of very moist to wet nutrient-rich areas, which result in a diverse shrub and forb layer. The variety of vegetation moisture is dry to slightly moist, drought-tolerant species have a competitive advantage.

In the Montane, species such as rough fescue, hairy wild rye, bearberry, juniper, Douglas fir or lodgepole pine occupy recharge areas. On dry, nutrient-poor sites, Douglas fir forms an open tree canopy with a well-developed grass layer (typically rough fescue and bearberry on exposed south-facing mountainsides where the water table is deep. In the Bow Valley, this association is found on the upper slopes of south-facing benchlands through much of the western half of the corridor and near Exshaw and Wind Valley.

On slightly moist, nutrient-poor sites, lodgepole pine, aspen and white spruce form pure and mixed stands, with a ground cover of juniper, bearberry and grasses and occasional shrubs or forbs. There is a slow succession toward white spruce. Trees are scattered between grasslands in drier sites and the canopy is closed where moisture conditions are better. Shrubs and forbs are sparse in wooded areas. This association is typical of portions of the benchlands and of the elevated outwash plain in the east.

Depletion of soil moisture and nutrients though groundwater recharge helps to maintain the grassland and open woodland areas. Where moisture conditions are better, and without renewal through periodic drought, fire, and grazing, Douglas fir, lodgepole pine and aspen give way to spruce. Spruce forests allow little light penetration, reducing the understory of shrubs and grasses to mosses. Berry production plummets, and fewer herbs and shrubs are available for grazers/browsers (Figure 6.2).

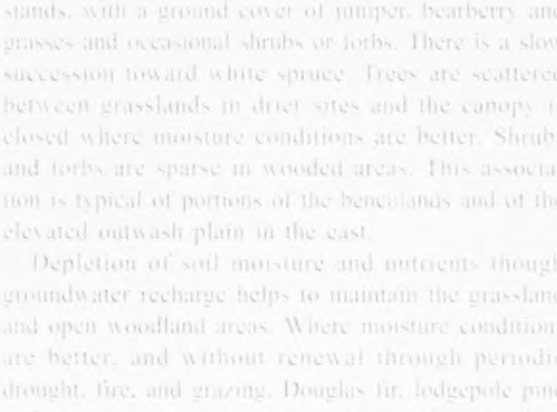


Figure 6.2 Generalized plant and animal assemblages for a groundwater recharge zone, Montane ecoregion.

In the Subalpine, lichens, juniper, bearberry, hairy wild rye and lodgepole pine are characteristic species of nutrient deficient-recharge areas. The largest area of this type is found in Wind Valley, on south-facing slopes of Pigeon Mountain (Figure 6.3).

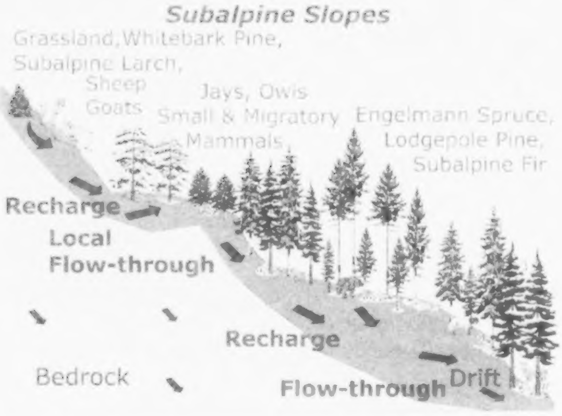


Figure 6.3 Generalized plant and animal assemblages for a groundwater recharge and lateral flow area, Subalpine ecoregion.

The grasslands and open woodland of Montane and Subalpine recharge areas provide habitat for a wide variety of animals, including elk, mountain sheep, deer, cougar, coyotes, birds, small mammals and rodents. Elk and bighorn sheep, in particular, favour these environments in winter.

Elk are generalist feeders of grasses, forbs, sedges and shrubs in winter and deciduous trees in summer. Since deep snow prevents grazing, elk favour dry open areas, exposed to sun and Chinook winds for fall and winter range (Skolvin, 1982). A population of 350 elk live in the Montane of the Canmore Corridor: 100 in the eastern outwash plain, 150 in Wind Valley/Pigeon Mountain and 100 interspersed through the benchlands (Alberta Forestry Lands & Wildlife, 1990).

Bighorn sheep favour the same wind-blown feeding areas as elk, however they also require cliffs and steep slopes to escape predators. Dry, barren slopes in recharge areas tend to have a greater slope because of the low degree of saturation, so they provide the right juxtaposition of feeding and escape habitat. As sheep are well adapted to higher elevations, they occupy both the Montane and Subalpine regions. A population of 300 bighorn sheep inhabits the Montane of the Bow Corridor, half on dry, south-facing slopes, particularly in the central corridor, and the other half on Douglas fir forests and grasslands on south-facing slopes of Wind Valley. Prime wintering habitat is also found on Mt. Allan and along other wind-blown, steep slopes in the Subalpine.

The healthy ungulate population of the recharge areas, particularly the Wind Valley region, helps to support a variety of carnivores including grizzly and black bears, wolverine, wolf, lynx, fox, coyote and cougar (University of Calgary, 1994; Alberta Environmental Protection, 1997b).

Flow-through areas

Dominantly lateral groundwater flow results in moist sites with a moderately enriched assemblage of nutrients, typical of middle to lower topography on gentle slopes. Transient groundwater recharge or seepage may occur after heavy rain or during spring runoff. Humus is well developed.

In the Montane region, aspen are typical of moderately moist, well-drained sites, often interspersed with white spruce. Lodgepole pine, Douglas fir and white spruce form pure and mixed stands on drier sites, while aspen and white spruce favour areas where moisture and nutrient conditions are better. This site supports a wide variety of plant communities including creeping mahonia, green alder, snowberry, pine grass and Schreber's moss on drier sites and dense shrubby understories of dogwood, low-bush cranberry, saskatoon and prickly rose on moist sites. Succession is toward white spruce. Disturbance can cause a rapid increase in shrub and forb cover, and favours primarily aspen, as well as lodgepole pine (Figure 6.4).

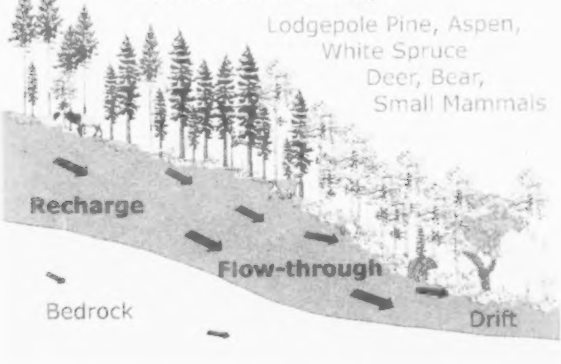

Montane Mid-Slope
Lodgepole Pine, Aspen, White Spruce
Deer, Bear, Small Mammals
Recharge
Flow-through
Bedrock
Drift

Figure 6.4 Generalized plant and animal assemblages for a lateral groundwater flow area, Montane ecoregion.

The woodlands of Montane flow-through areas provide biologically diverse habitat for Columbian ground squirrel, red squirrel, meadow vole, ruffed grouse, warbling vireo, downy woodpecker, elk, mule, and white-tailed deer and numerous birds (Holland and Coen, 1983), as aspen woodland is second only to riparian forest in terms of overall diversity. Aspen and deciduous shrubs are a favoured food of browsing deer and elk, and beaver. Buffalo berries grow best under the open canopy of scattered deciduous woodland, where they provide a high-energy seasonal food source critical to species like black bears that are trying to build up energy stores for reproduction and hibernation.

Flow-through conditions are typical of much of Yamnuska Natural Area, one of the most ecologically diverse areas of Alberta. Mixed woodland is interspersed with grasslands and, in some places, small lakes and ponds, fens and beaver ponds. It is home to an unusually wide range of plant species, some rare or uncommon. There are 362 documented vascular plants: 9 are rare, and 11 uncommon. It hosts over 180 species of butterflies and moths. There are 14 distinct vegetation communities. The area is spring calving range for elk, which migrate from their grassland wintering grounds to wooded areas that provide cover for their young (Alberta Environment, 1999).

In the Subalpine, flow-through areas of scattered subalpine larch, subalpine fir, heather and grouseberry occur in moist, nutrient-poor sites, generally in cirque valleys near timberline. Such sites are small, rare and scattered in the Bow Valley-Kananaskis region. The valley of the ten peaks (Larch Valley) near Lake Louise in Banff National Park is a classic example on a larger scale. More typical mid-slope vegetation are lodgepole pine on disturbed or burnt sites succeeded by Engelmann spruce and subalpine fir. Other species include grouseberry, false azalea, thimbleberry, green alder and pine grass. The generally closed forests in the subalpine zone are less conducive to wildlife, but are home to such forest species as lynx, snowshoe hare, Canada jay and small mammals (Figure 6.5).

Discharge areas

Regions of groundwater discharge occur in relative topographic lows, particularly in valley bottoms, near rivers and streams, and ponds. Groundwater seepage and high water tables are characteristic of very moist to wet nutrient-rich areas, which result in a diverse shrub and forb layer. The variety of vegetation communities is mostly controlled by water table (Timoney, 1991).

In the Montane region, balsam poplar, willow, swamp birch, snowberry, baneberry, dogwood and horsetail are key indicators of moist to wet nutrient-rich conditions. Balsam poplar is the pioneer species, especially on well-drained sites; white spruce is the climax species, but is slow to establish itself. Disturbance through flooding helps to maintain the competitive advantage of deciduous species because white spruce seedlings cannot tolerate flooding.

In the Bow River valley, wetlands occupy relatively flat terrain dominated by the Bow River and its groundwater-fed ponds and tributaries. More than half the valley wetland area known as Bow Flats is dominated by mature white spruce, with an understory of wolf willow and associated grass-like meadows. Mixed-wood stands of mature balsam poplar, aspen and white spruce, with a dense understory, are also common. Shrub willow and birch communities, sedge and brown moss meadows, herbs and hair grass are found in wetter sites (Figure 6.5).

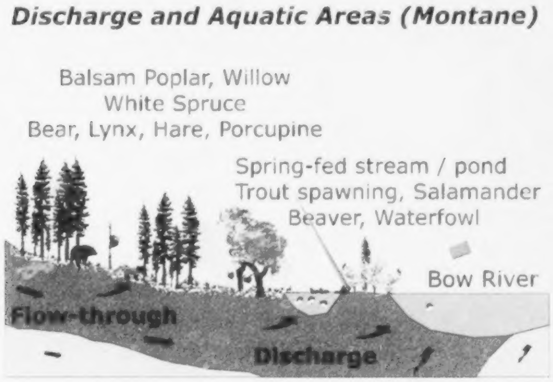

Discharge and Aquatic Areas (Montane)

Figure 6.5 Generalized plant and animal assemblages for groundwater discharge areas, Montane ecoregion.

In the Subalpine, moist to wet nutrient-rich sites of discharge areas have the highest diversity of plant species. Where seepage is seasonal, Engelmann spruce, lodgepole pine and subalpine fir are the dominant tree species; they form an open canopy. Shrubs and forbs are more diagnostic vegetation of this environment; they include thimbleberry, baneberry, false hellebore and heart-leafed arnica. Where seepage and water tables are high, fens occur. Characteristic species are scattered Engelmann spruce, dwarf birch, willow, horsetail, sedges, hair grass and mosses. Because discharge sites tend to be low lying, tree growth is limited by cool temperatures brought on by cold air drainage (Figure 6.6).

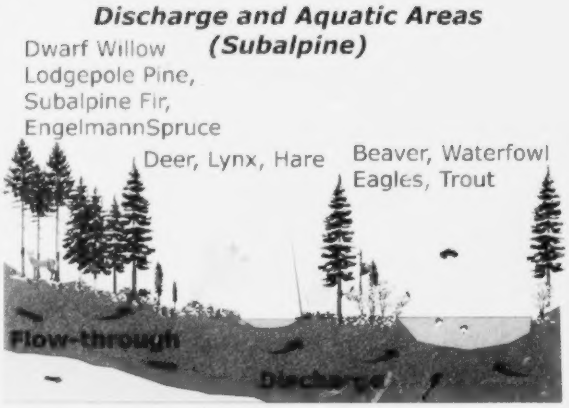

Discharge and Aquatic Areas (Subalpine)

Figure 6.6 Generalized plant and animal assemblages for groundwater discharge areas, Subalpine Ecoregion.

Wetland and floodplain areas host the widest diversity of wildlife in the Bow Valley (Alberta Environmental Protection, 1997a). Elk use the area for spring calving (O'Leary, 1988), and mule deer favour the ecotone between forest and grassland communities. Moose are surprisingly rare in the valley, despite highly favourable habitat, probably because of disease and the isolation caused by transportation corridors. Aquatic habitats are populated by beavers, which often dam spring waters in old channels, and by muskrats and mink. Porcupines, snowshoe hares, squirrels and chipmunks live in the spruce forests, providing food for marten, lynx, cougars, black bears and coyotes. The wetlands are highly productive for breeding birds and are home to 48 species, including uncommon birds, such as hooded mergansers, bald eagles, willow flycatchers, calliope hummingbirds, ospreys and fox sparrows.

Fens fed by the springs are important spring and summer feeding areas for ungulates and bears. The fen in west Wind Valley creek is the largest of its kind in the Banff-Kananaskis region, consisting of low, erect shrubs and an open-tree canopy. Mineral licks related to groundwater discharge attract elk, sheep, occasional deer and their predators. A population of grizzly and black bears frequent the area in spring and summer, attracted to horsetail, which is a seasonal staple of their diet (University of Calgary, 1994; Alberta Environmental Protection 1997a). Smaller wetland areas and fens occur outside of the Bow River floodplain. Calcareous wetlands—associated with springs and seepages such a those found along Exshaw Creek, at the base of Pigeon Mountain and in Yamnuska Natural Area—are home to rare and uncommon specialized plants, including orchids, mountain maple, rare ferns, communities is mostly controlled by water table (Timoney, 1991).

In the Montane region, balsam poplar, willow, swamp birch, snowberry, baneberry, dogwood and horsetail are key indicators of moist to wet nutrient-rich conditions. Balsam poplar is the pioneer species, especially on well-drained sites; white spruce is the climax species, but is slow to establish itself. Disturbance through flooding helps to maintain the competitive advantage of deciduous species because white spruce seedlings cannot tolerate flooding.

In the Bow River valley, wetlands occupy relatively flat terrain dominated by the Bow River and its groundwater-fed ponds and tributaries. More than half the valley wetland area known as Bow Flats is dominated by mature white spruce, with an understory of wolf willow and associated grass-like meadows. Mixed-wood stands of mature balsam poplar, aspen and white spruce, with a dense understory, are also common. Shrub willow and birch communities, sedge and brown moss meadows, herbs and hair grass are found in wetter sites (Figure 6.5).

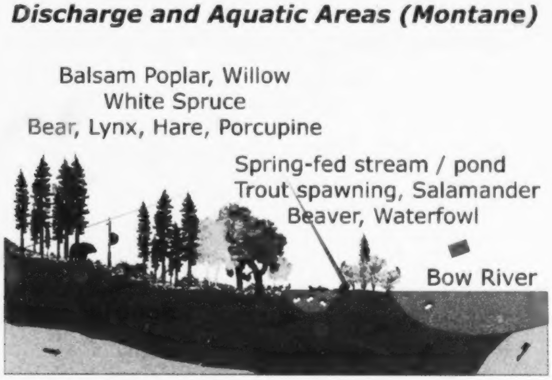

Discharge and Aquatic Areas (Montane)
Balsam Poplar, Willow
White Spruce
Bear, Lynx, Hare, Porcupine
Spring-fed stream / pond
Trout spawning, Salamander
Beaver, Waterfowl
Bow River

Figure 6.5 Generalized plant and animal assemblages for groundwater discharge areas, Montane ecoregion.

In the Subalpine, moist to wet nutrient-rich sites of discharge areas have the highest diversity of plant species. Where seepage is seasonal, Engelmann spruce, lodgepole pine and subalpine fir are the dominant tree species; they form an open canopy. Shrubs and forbs are more diagnostic vegetation of this environment; they include thimbleberry, baneberry, false hellebore and heart-leafed arnica. Where seepage and water tables are high, fens occur. Characteristic species are scattered Engelmann spruce, dwarf birch, willow, horsetail, sedges, hair grass and mosses. Because discharge sites tend to be low lying, tree growth is limited by cool temperatures brought on by cold air drainage (Figure 6.6).

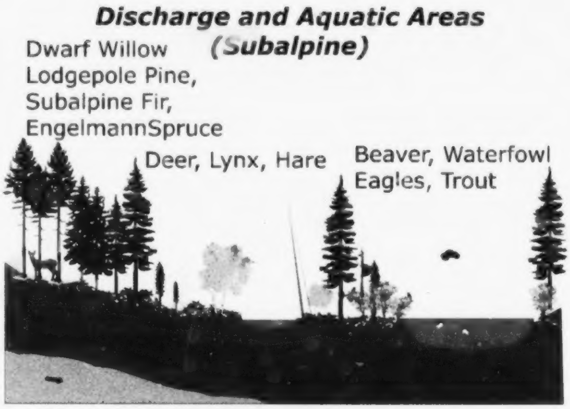


Figure 6.6 Generalized plant and animal assemblages for groundwater discharge areas, Subalpine Ecoregion.

Wetland and floodplain areas host the widest diversity of wildlife in the Bow Valley (Alberta Environmental Protection, 1997a). Elk use the area for spring calving (O'Leary, 1988), and mule deer favour the ecotone between forest and grassland communities. Moose are surprisingly rare in the valley, despite highly favourable habitat, probably because of disease and the isolation caused by transportation corridors. Aquatic habitats are populated by beavers, which often dam spring waters in old channels, and by muskrats and mink. Porcupines, snowshoe hares, squirrels and chipmunks live in the spruce forests, providing food for marten, lynx, cougars, black bears and coyotes. The wetlands are highly productive for breeding birds and are home to 48 species, including uncommon birds, such as hooded mergansers, bald eagles, willow flycatchers, calliope hummingbirds, ospreys and fox sparrows.

Fens fed by the springs are important spring and summer feeding areas for ungulates and bears. The fen in west Wind Valley creek is the largest of its kind in the Banff-Kananaskis region, consisting of low, erect shrubs and an open-tree canopy. Mineral licks related to groundwater discharge attract elk, sheep, occasional deer and their predators. A population of grizzly and black bears frequent the area in spring and summer, attracted to horsetail, which is a seasonal staple of their diet (University of Calgary, 1994; Alberta Environmental Protection 1997a). Smaller wetland areas and fens occur outside of the Bow River floodplain. Calcareous wetlands—associated with springs and seepages such a those found along Exshaw Creek, at the base of Pigeon Mountain and in Yamnuska Natural Area—are home to rare and uncommon specialized plants, including orchids, mountain maple, rare ferns, sundew and buck bean (Sweetgrass Consultants Ltd., 1991), and birds such as yellowlegs and solitary sandpipers (Alberta Environment, 1999).

Aquatic and riparian areas

Groundwater stabilizes the aquatic environment by sustaining spring flow and baseflow to streams and lakes, moderating temperatures, providing a reliable nutrient supply, providing moisture to riparian areas and controlling the stability of riverbanks.

Springs serve as important water sources for wetlands and as the headwaters for tributary streams that, together with seepage, maintain the base level of permanent streams and ponds. Springs may show seasonal variations in yield, temperature and chemistry (Van Everdingen, 1972), but these variations are minor in comparison to fluctuations in surface waters. High-volume springs maintain areas of open water throughout the winter and moderate root zone temperatures for aquatic and peripheral plants.

Nitrate and phosphorus occur naturally, but the Bow River has very little of either. Phosphate is not common in the mountain environment, and most of the phosphorus in Alberta comes from the mineral apatite. Inputs of even small amounts can increase vegetative growth and vigour of aquatic plants.

Nitrate concentrations above the detection limit are often indicative of contamination from sewage or fertilizers. However, neither source can explain the widespread distribution of low levels of nitrates characteristic the Bow Valley-Kananaskis region; they likely arise from slow oxidation of organic debris in the near-surface environment.

Nitrates are fairly mobile in an oxygenated environment and readily enter the groundwater regime through soil leaching, so they are higher in streams fed primarily by baseflow. Peterjohn and Correll (1984) found that riparian zones are effective at removing nitrates from groundwater through vegetative uptake and possibly denitrification by anaerobic bacteria, reducing nitrate discharge into surface water bodies. Dawson and Ehleringer (1991) showed that riparian tree species in Utah selectively used groundwater over surface water, even when surface water was abundant.

Aquatic areas and marginal wetlands occur on floodplains and near areas of concentrated groundwater discharge. The ready availability of water and nutrients, combined with the moderated temperature, supports lush vegetative growth, which is maintained by the consistently high water table of groundwater discharge zones. This is particularly important to larger and older growth along the floodplain. Growth along stream banks is normally smaller and younger because of flood disturbance. Riparian vegetation strengthens banks, limiting erosion, and intercepts sediment-laden surface runoff while removing nutrients from groundwater, thereby maintaining or improving river water quality. It also provides food for aquatic invertebrates and shades the river margins, providing sheltered spots for fish and other aquatic species (Figure 6.5).

Springs

Springs are special discharge areas. Locally, they provide higher humidity and an abundance of soil moisture that promotes lush vegetative growth. Combined with the warmer temperature of the spring, the resulting vegetation provides shelter from the elements and consequently a milder microclimate. Springs also deposit minerals that support unique or rare plant communities, and they create or enhance year-round water bodies that benefit the survival of many aquatic animals.

Most springs of the Canmore Corridor and Northwest Kananaskis Country have a steady temperature of between 2° and 5° C, but occasionally "warm springs" may reach temperatures between 7° and 12° C, peaking in late winter before the snow melts. With the exception of Many Springs, most warm springs in this region have relatively low flows and consequently affect a small area.

Several microclimates are found in the area. A dramatic example is found near the Watridge Karst Spring in Spray Valley Provincial Park. The large, relatively constant temperature flow cascades down the mountainside, creating a high-humidity environment that supports an open forest of large trees of old-growth spruce, moss-covered boulders and moisture-loving shrubs. Enhanced environments are also found at Willow Rock Spring and Illahee Spring in Bow Valley Provincial Park, where the outwash plain begins to slope toward the Kananaskis River. There, the land above the springs is dry grassland with scattered aspen; below the springs, it is a dense, moist forest.

Aside from providing a warm, moist environment, springs deposit minerals that provide habitat for specialized plant types, particularly those that are dependent on a high pH. The Many Springs area supports many fen plants with particular environmental requirements. The yellow lady's slipper orchid, which is common at Many Springs, is a prime example.

Lady's slipper orchids are among the rare plants that find a specialized environment near springs.

The mineral deposits also provide licks for wildlife, such as sheep and moose, and the resulting fen vegetation provides food for ungulates and nesting cover for waterfowl. Lac des Arcs and Gap Lake, fed by high volume and warm springs, are important waterfowl staging areas in spring and fall for Canada goose, bufflehead, common goldeneye, common merganser, common loon and mallard.

Springs in the area provide important habitat for rare aquatic insects and amphibians, and prime spawning sites for key fish species. For example, at Many Springs, aquatic arthropods, such as Salmasellus steganothrix, depend on the unique temperature range for their survival in the region.

In Bow Valley Provincial Park, the isolated, spring-fed water bodies of Middle Lake, Chilver Lake and adjacent ponds provide critical habitat for long-toed and tiger salamanders, which require reliable water bodies that are free from the predators found in water bodies that are connected by streams. And, the Bow Valley floodplain between Canmore and Dead Man's Flats contains a series of spring-fed creeks, such as Policeman's Creek, Spring Creek and Bill Griffiths Creek, that provide the most significant trout-spawning grounds in the Bow River system because of their constant temperature (near 5° C) and naturally filtered, clear water.

Summary

The Bow Valley-Kananaskis region constitutes a relatively small, partially enclosed basin area, where groundwater is a dominant portion of the hydrologic cycle. Significant topographic variation drives groundwater flow systems from the high-mechanical-energy environment of the Alpine and Subalpine ecoregions to the low-mechanical-energy environment of the Montane. While Alpine and Subalpine ecoregions are sustained primarily by the heavy precipitation that occurs at high elevations, most of the water supplying the Montane is received from groundwater transport from higher elevations. Groundwater mobilizes nutrients and heat from recharge zones at higher elevations, and transports and deposits them to discharge areas of the valley bottoms.

Variations in moisture and nutrient supplies affect the distribution and composition of vegetative assemblages. These vegetative assemblages attract various wildlife species, looking for favourable food supplies and cover from the elements and predators. In aquatic systems, groundwater sustains base flow, and provides appropriate habitat for fish spawning and open water for waterfowl. As such, groundwater forms an integral and essential component of the region's ecosystems.

Marmot Basin Hydrology Study

Watershed research program

The eastern slopes of the Rocky Mountains form the primary watershed for the prairies, supplying the majority of flow in the Saskatchewan River drainage basin. The Eastern Rockies Forest Conservation Board (ERFCB) was established in 1947 with a mandate for "the conservation, development, maintenance and management of the forests in such area with a view to obtaining the greatest possible flow of water in the Saskatchewan River and its tributaries" (Parliament of Canada, 1947). Out of this mandate came the Eastern Slopes Watershed Research Program, and the Marmot Creek Experimental Basin, a comprehensive basin study that spanned nearly a quarter century.

The Marmot Creek Experimental Basin study intended first to establish the baseline physical characteristics and hydrology of drainage within undisturbed spruce/fir forest, with emphasis on the relationships between precipitation, runoff, evapotranspiration and groundwater within the basin. It was then to determine the effects of timber harvesting practices on snow pack accumulation, timing and volume of runoff, basin yield, water quality and subsequent forest regrowth. The goal was improved logging practices and cut block geometry for watershed management. The study was headed by Environment Canada in various partnerships that changed over the years with federal and provincial agencies, each studying aspects of meteorology, hydrology, hydrogeology, forestry and wildlife. The number of papers and reports generated by the research program fill an extensive bibliography. Aspects of research related to groundwater are discussed in this review.

The study involved the mapping of basin topography, soils, plant cover and surficial and bedrock geology. Instrumentation was installed to measure weather conditions, precipitation, stream flow and groundwater levels for the determination of the water budget. For many years the Marmot Creek basin was reputably the most heavily instrumented basin in Canada. Readings were taken for air temperature, relative humidity, solar radiation, precipitation and wind speed and direction, measured at four permanent stations. Ten snow pillows were measured monthly in winter. Five weirs monitored flow on the Marmot Creek and its tributaries. Forty shallow groundwater monitoring wells were installed over the lifetime of the program, mostly in drift in the lower part of the basin, with a few added in later years once roads were constructed to higher elevations. Even wildlife were monitored within the basin, which is part of the wildlife corridor connecting the Bow and Kananaskis valleys. Most of the research was conducted from the late 1960s into the mid 1970s.

In the summer of 1984, clearing began for the Nakiska ski hill on Mount Allan in preparation for the 1988 Winter Olympic Games. The development encroached on the southern portion of the basin, with plans for long-term expansion. After a review, the Marmot Creek Experimental Basin study was ended in 1986. Meteorological, hydrometric and groundwater monitoring sites were closed, and the groundwater wells reclaimed. Three wells were retained beyond 1986 in Alberta Environment's monitoring well network. Record keeping for these wells ceased in 1997.

Although the Marmot Basin study was not part of our work, it provides a significant model of hydrological and environmental processes in the Canmore Corridor-Northwest Kananaskis Country region, with strong implications to current research. Findings from the study were considered significant enough to our work for us to provide this overview chapter.

Basin setting

The Marmot Creek Basin occupies the eastern slope of Mount Allan in the Kananaskis Valley covering Sections 10, 11, 14 and 15 of Township 23, Range 9 west of the 5th Meridian. The basin is 9.4 square kilometres in area and has an average slope of 39%. The upper limit of the basin is the Mt. Allan summit, an elevation of 2819 metres. The basin is comprised of three sub-basins drained by tributary streams, which merge in a confluence area in the lower basin (Figure 7.1).

Twin Creek, the southern sub-basin, covers an area of 2.62 km^2. Middle Fork Creek, 2.85 km^2, occupies the central sub-basin. Cabin Creek, the northern sub-basin, covers an area of 2.12 km^2. The three creeks originate in the alpine zone, issuing from the bases of scree slopes and eroding v-shaped gullies into the underlying bedrock. Below 1890 m, the slope is gentler. Downstream, these channels are incised through the thick moraine into the underlying bedrock. Twin

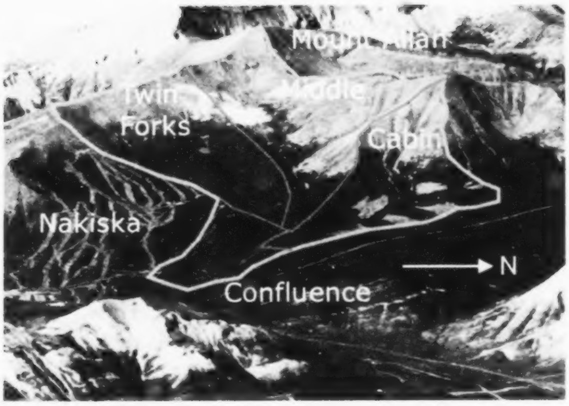


Figure 7.1 Aerial view of the Marmot Creek Experimental Basin, looking west. The three subbasins are Twin Forks, Middle and Cabin; the three streams join at the Confluence. The Nakiska Ski hill, developed in the 1980s, can be seen on the left.

and Middle Fork Creek merge to form Marmot Creek just below 1770 m elevation, and Cabin Creek joins at 1700 m. The confluence area covers 1.81 km^2. Marmot Creek continues in a deep channel to the basin outlet at 1585 m. It descends another 120 m to an alluvial fan above the Kananaskis River.

At the height of the study in the late 1960s, up to 33 rain gauges and 20 snow courses were monitored (Storr, 1977). Annual precipitation averages 900 mm, increasing from 600 mm in the lower basin to over 1140 mm in the upper reaches of Twin Creek (Storr 1967) and average annual evapotranspiration is about 440 mm. Approximately 75 percent of the precipitation occurs as snow, none of which is stored from one year to the next. Snow pack accumulation is affected by elevation, aspect, slope and forest density, with total mean snow pack increasing at a predictable rate with elevation Golding (1969). The basin is representative of much of the Subalpine and Alpine zone of the Bow Valley-Kananaskis region.

Basin geology

Marmot Basin rests on the east limb of the Mount Allan Syncline. It is underlain by shale, sandstone, coal and conglomerate ranging in age from Permian to Lower Cretaceous. A resistant bench of hard quartzite and cherty dolomite of the Rocky Mountain Group forms the lower boundary of the basin. The top boundary of the basin is resistant Kootenay sandstone and Blairmore Group conglomerate. Softer shales and siltstones of the Sulphur Mountain Formation, Fernie and Kootenay formations underlie most of the intervening area (Stevenson, 1967).

Glacial and post-glacial surficial deposits blanket the bedrock except at high elevations and a few outcrops along creek channels. Accumulations of talus and scree are found below steep bedrock slopes and cirque moraines of clay, silt and boulders occur at higher elevations. Locally derived Kananaskis Valley till 10 m thick is found between ridges of recessional moraine, which are up to 30 m thick. Surficial deposits are mainly poorly sorted silty and stony clay till, interspersed with boulders. Colluvium and alluvium blanket the till in places. Alluvium is deposited where streams encounter local depressions and consists of fine sands and silts, particularly in the confluence area. Coarse angular boulders up to eight metres deep fill extensive reaches of the stream channels, likely originating as slumps, slides, soil creep and rock avalanche, where the fines were washed away (Stevenson, 1967).

Hydrology

The Water Survey of Canada operated stream gauges on the three tributaries of Marmot Creek and on the main stem continuously for the duration of the study (Hydrocon, 1984). Minimum stream flow occurs in late March and is usually less than 30 L/s. Spring snowmelt begins at low elevations and gradually moves upslope, into heavier snowpack areas. Snowmelt typically starts in late April to early May and peaks in early June, continuing into mid-summer from sheltered high elevation sites, notably Marmot cirque. Through spring and summer, stream flow is derived from snowmelt, rainfall, storm seepage and groundwater storage. The mean total runoff from May through September was recorded as 364 mm for Marmot Creek, 433 mm for Middle Fork Creek, 455 mm for Twin Creek and 287 mm for Cabin Creek (1963-1984), accounting for 85-95% of total annual runoff and 100% of the suspended sediment load. Flows from late fall through winter were low but steady. Fifty percent of the annual precipitation is accounted for as stream flow (Swanson et al., 1984).

Surface water in the streams is primarily calcium-magnesium-bicarbonate type. The water in Cabin Creek water is harder and more highly mineralized than the other sub-basins, possibly because of a larger baseflow contribution and its situation primarily in the subalpine zone. Middle Fork Creek and Twin Creek receive a higher contribution of water from alpine snowpacks. Mineralization was inversely propor-

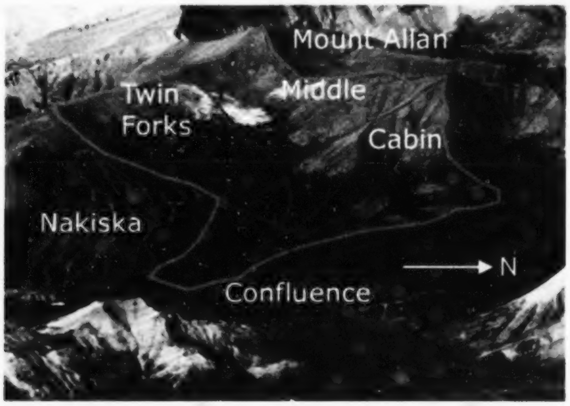


Figure 7.1 Aerial view of the Marmot Creek Experimental Basin, looking west. The three subbasins are Twin Forks, Middle and Cabin; the three streams join at the Confluence. The Nakiska Ski hill, developed in the 1980s, can be seen on the left.

and Middle Fork Creek merge to form Marmot Creek just below 1770 m elevation, and Cabin Creek joins at 1700 m. The confluence area covers 1.81 km^2. Marmot Creek continues in a deep channel to the basin outlet at 1585 m. It descends another 120 m to an alluvial fan above the Kananaskis River.

At the height of the study in the late 1960s, up to 33 rain gauges and 20 snow courses were monitored (Storr, 1977). Annual precipitation averages 900 mm, increasing from 600 mm in the lower basin to over 1140 mm in the upper reaches of Twin Creek (Storr 1967) and average annual evapotranspiration is about 440 mm. Approximately 75 percent of the precipitation occurs as snow, none of which is stored from one year to the next. Snow pack accumulation is affected by elevation, aspect, slope and forest density, with total mean snow pack increasing at a predictable rate with elevation Golding (1969). The basin is representative of much of the Subalpine and Alpine zone of the Bow Valley-Kananaskis region.

Basin geology

Marmot Basin rests on the east limb of the Mount Allan Syncline. It is underlain by shale, sandstone, coal and conglomerate ranging in age from Permian to Lower Cretaceous. A resistant bench of hard quartzite and cherty dolomite of the Rocky Mountain Group forms the lower boundary of the basin. The top boundary of the basin is resistant Kootenay sandstone and Blairmore Group conglomerate. Softer shales and siltstones of the Sulphur Mountain Formation, Fernie and Kootenay formations underlie most of the intervening area (Stevenson, 1967).

Glacial and post-glacial surficial deposits blanket the bedrock except at high elevations and a few outcrops along creek channels. Accumulations of talus and scree are found below steep bedrock slopes and cirque moraines of clay, silt and boulders occur at higher elevations. Locally derived Kananaskis Valley till 10 m thick is found between ridges of recessional moraine, which are up to 30 m thick. Surficial deposits are mainly poorly sorted silty and stony clay till, interspersed with boulders. Colluvium and alluvium blanket the till in places. Alluvium is deposited where streams encounter local depressions and consists of fine sands and silts, particularly in the confluence area. Coarse angular boulders up to eight metres deep fill extensive reaches of the stream channels, likely originating as slumps, slides, soil creep and rock avalanche, where the fines were washed away (Stevenson, 1967).

Hydrology

The Water Survey of Canada operated stream gauges on the three tributaries of Marmot Creek and on the main stem continuously for the duration of the study (Hydrocon, 1984). Minimum stream flow occurs in late March and is usually less than 30 L/s. Spring snowmelt begins at low elevations and gradually moves upslope, into heavier snowpack areas. Snowmelt typically starts in late April to early May and peaks in early June, continuing into mid-summer from sheltered high elevation sites, notably Marmot cirque. Through spring and summer, stream flow is derived from snowmelt, rainfall, storm seepage and groundwater storage. The mean total runoff from May through September was recorded as 364 mm for Marmot Creek, 433 mm for Middle Fork Creek, 455 mm for Twin Creek and 287 mm for Cabin Creek (1963-1984), accounting for 85-95% of total annual runoff and 100% of the suspended sediment load. Flows from late fall through winter were low but steady. Fifty percent of the annual precipitation is accounted for as stream flow (Swanson et al., 1984).

Surface water in the streams is primarily calcium-magnesium-bicarbonate type. The water in Cabin Creek water is harder and more highly mineralized than the other sub-basins, possibly because of a larger baseflow contribution and its situation primarily in the subalpine zone. Middle Fork Creek and Twin Creek receive a higher contribution of water from alpine snowpacks. Mineralization was inversely proportional to stream stages, increasing in March and decreasing in June.

Forestry and forest hydrology

Forest cover is mainly old growth spruce and fir over 200 years old. Homogenous stands of lodgepole pine are found in the confluence area, resulting from a fire in 1936. Alpine larch and trembling aspen are found in a few locations. Spruce-fir forest extends to the 2100 m elevation, followed by forests of subalpine larch and fir to the timberline at 2285 m. Around 48% of the basin is shrub, meadow and rock, considered unproductive for forestry. Around 41% is spruce-fir and 9% is young lodgepole pine. Soils are poorly developed mountain luvisols at lower elevations and podzols and regosols at higher elevations (Kirby and Ogilvie, 1969).

In late 1974, 21% of the Cabin Creek sub-basin was clearcut in six 10 ha commercial-sized blocks. Annual water yield increased between 6 and 7% (16.8 mm) over what was predicted if it had been left uncut—an additional 79 mm from the clearcuts. Erosion was not a problem. Between 1977 and 1979, about 40% of the forest in the Twin Creek Sub-basin was cleared, using a "honeycomb" pattern of 2103 circular openings 15 or 20 m in diameter. The pattern was selected to keeping the area shaded by surrounding trees, delaying snowmelt and favouring late season streamflow. The annual water yield increased by 36 mm in 1980 and 16 mm in 1981, the increase resulting entirely from deeper snowpack in the clearings (Swanson and Golding, 1982; Hydrocon, 1985). Clearing for the Nakiska ski hill began in 1985 along the south edge of the Twin Creek basin, disturbing the study area and ending the study. The Middle Fork Creek sub-basin was left intact as a control area.

Water balance

Water balance baseline data collected between 1964 and 1974 revealed a large residual when stream flow and evapotranspiration were subtracted from the annual precipitation. Storr (1974) correlated the residual with changes in water levels seen in the groundwater hydrographs, accounting for up to 12% of precipitation. The poorly accessible terrain prohibited direct measurement of changes in groundwater storage. The soil zone is shallow and soil moisture is negligible. Storr correlated groundwater storage to stream flow. Where there was no surface flow to the streams, the rate of stream flow was set as an index of the amount of groundwater storage. The higher the level of the groundwater reservoir, the greater the proportion of discharge from groundwater to the stream at all points along the channel.

Based on the integration of groundwater discharge into the channel over the upstream area as a function of the size of the reservoir, Storr calculated a maximum reservoir capacity of 265 mm, which is reached at a flow of about 0.7 m^3/s. Runoff would normally occur only in June from the combination of rapid snowmelt and heavy rainfall. For the remainder of the year, storage is below capacity and the high infiltration rate prevents direct flow into the channels.

The coarse glacial deposits usually had minimum infiltration rates higher than maximum reported storm intensities (Beke, 1969). Lower infiltration rates were reported for surface materials derived from shale bedrock. Application of standard hydrograph separation techniques showed that less than 2% of annual flow was surface runoff from rainfall (Hewlett and Hibbert, 1967). Swanson et al. (1984) concluded that most of the Marmot Creek stream flow was fed by transient subsurface flow (interflow) from glacial deposits, which had a moderating effect on storm peaks.

Groundwater monitoring

From 1964 to 1965, 18 water table wells and 8 nested piezometers were installed by rotary rig at 17 sites in the lower, accessible reaches of the basin. The wells were constructed of four-inch steel pipe with torch slots, later replaced by screens. Piezometers were two-inch steel pipe with sand points. The wells and most of the piezometers were completed less than 12 m deep in drift. Chart recorders were installed on thirteen water table wells and one piezometer. The rest were monitored manually. Monitoring of most of the wells was discontinued in 1971.

Water table wells completed in the glacial deposits of the confluence area fluctuated rapidly in response to spring runoff and storm events, indicating the deposits have high infiltration capacity and low water retention. Wells completed in morainal ridges were less responsive and had significantly smaller fluctuations indicating lower hydraulic conductivities. Wells in stream deposits had fairly stable water levels. Water level readings from four sites having nested piezometers were studied to determine the hydraulic connection between the till and the bedrock. Correlations were noted at two of the sites, but were not conclusive enough to establish any significant relationship (Stevenson, 1971).

A total of 40 wells are on record in the Alberta Environment database (Figure 7.2). No published analysis is available for wells drilled in later phases of the study. Six wells were incorporated into the Alberta Environment groundwater monitoring well network, three of which continued to record water levels until 1997 (Table 7.1). With the exceptions of numbers 302 and 304, the wells were suspended, but have not been reclaimed, constituting the only remaining monitoring infrastructure at Marmot Creek. Charts of the monitoring wells are located in Appendix A. Locations of wells are shown in Figure 7.2.

Table 7.1 Alberta Environment monitoring wells.

Number	Name	Subbasin	Depth	Start Date	End Date
302	Marmot Creek Basin S5430	Confluence Area	9.1 m	Oct 11, 1964	Dec 1, 1986
303	Marmot Creek Basin N5475	Confluence Area	36.6 m	July 9, 1965	July 23, 1997
304	Marmot Creek Basin S6170	Confluence Area	12.2 m	July 12, 1965	Nov 22, 1986
305	Marmot Creek Basin S6770	Cabin Creek	14.3 m	July 14, 1965	July 16, 1996
386	Marmot Creek Basin S2507E	Twin Creek	12.8 m	April 30, 1989	July 23, 1997

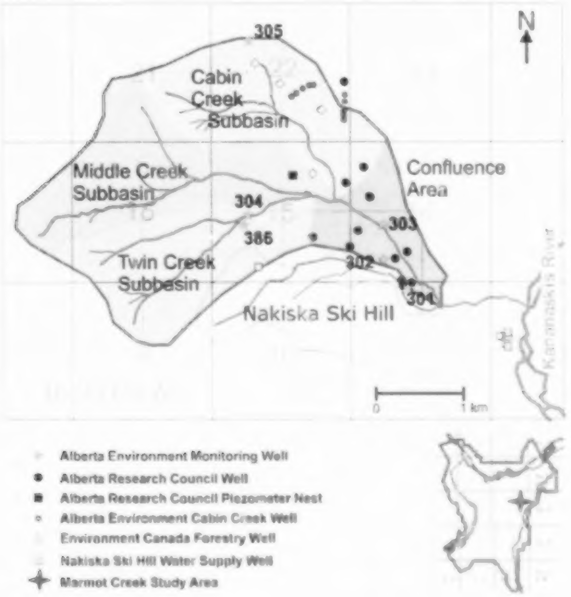

N
305
Cabin Creek Subbasin
Middle Creek Subbasin
304
386
Confluence Area
303
302
304
Twin Creek Subbasin
Nakiska Ski Hill
Kananaskis River
0
1 km
Alberta Environment Monitoring Well
Alberta Research Council Well
Alberta Research Council Piezometer Nest
Alberta Environment Cabin Creek Well
Environment Canada Forestry Well
Nakiska Ski Hill Water Supply Well
Marmot Creek Study Area

Figure 7.2 Locations of wells in the Marmot Creek Experimental Basin, designated by well owner. Wells incorporated into the Alberta Environment groundwater monitoring network are designated by Monitoring Branch well number.

Hydrogeology

The Marmot Creek basin forms an unconfined groundwater system, where water is stored and moves in surficial deposits draped over bedrock. Groundwater that discharges from joints in exposed bedrock is fine seepage, suggesting low matrix porosity; however localized folding and faulting have to potential to create hydraulically significant fracture networks. The bedrock appears to have minimal interaction with the groundwater in the overlying drift, although its structure influences stream geometry.

Water table divides closely approximate topographic divides, and groundwater flow mostly parallels the slope of topography. Near the top of the basin where slopes are steep and surficial deposits are thin to nonexistent, most precipitation is converted to runoff and shallow lateral flow. The tributary creeks arise as springs in the hillsides of the alpine zone from scree and talus. Recharge occurs in spring and early summer from snowmelt, spring rains and occasional late season storms. For most of the basin, surficial deposits have a high infiltration capacity and surface runoff is negligible. The level of the water table rises and falls in direct response to precipitation and is close to the land surface. Seepage and springs are common in low-lying areas, breaks in slope and in the v-shaped creek valleys. Water is continuously removed from the groundwater system by evapotranspiration and by baseflow seepage to the creeks. Stream flow is derived almost entirely from baseflow and interflow. Fluctuations on most of the groundwater hydrographs correspond directly to fluctuations on stream flow (Davis, 1964; Stevenson, 1971).

The groundwater type is calcium-magnesium-bicarbonate. Total dissolved solids average 265 mg/L, with an average hardness of 4. The proportions of major cations are 20-60% magnesium, 40-80% calcium, with negligible sodium. Anions are in the range of >80% bicarbonate, <20% sulphate and <5% chloride. Iron averages 5.5 mg/L, but this high value may reflect rusting of steel casings. Nitrate occurs only in trace amounts. The samples have a relative concentration of ions that is reasonably characteristic of groundwater found elsewhere in the region and of Bow River water. Similarities may be attributed to the glacial sediments that constitute the aquifer, which are a somewhat homogenized sampling of the region's bedrock geology. The major differences are a lower total dissolved solids and lower relative concentrations of sodium, chloride and to a lesser degree sulphate; differences that are mainly attributed to the relatively short residence time in the subsurface and immature geochemical evolution compared to samples collected from the valley bottom.

Conclusions

The Marmot Creek Experimental Basin constitutes a significant small-scale model of groundwater hydrology in the mountainous environment. In the Bow Valley-Kananaskis region as a whole, bedrock is primarily a confining layer, forming the base of the groundwater basin. The participation of bedrock in the water balance, is relatively minor, except where there is significant faulting and fracturing. Highly porous and permeable surface materials constitute the main aquifers in the region. The aquifers typically have the water table as the upper surface and interact readily with the land surface. Recharge occurs in late spring through snowmelt and spring storms. Runoff is minimal and infiltration high. Groundwater acts as a dominant conveyor of water in the basin, capturing precipitation from higher elevations and redistributing it to the valleys where it sustains stream flow and surface water bodies. Groundwater chemistry resembles that of other parts of the region, although in an immature state of geochemical evolution.

The Water Resource: Human Interactions

Current trends in water useage

The Rocky Mountains represent the main source of flow to the rivers that water the prairies. The Bow River that flows through Canmore provides drinking water to the City of Calgary and irrigates farmland to the east of the city. It joins the South Saskatchewan River that flows through the City of Medicine Hat and into Saskatchewan. Thus, impacts to the water resource in the headwaters may affect over one million users downstream.

The growth occurring in the Canmore region is increasing demand on the water supply near the headwaters of the Bow River. The amount of consumption has not been determined, but water licences give an indication of use. Major water users, such as municipalities, resorts and industries are required to obtain a licence from Alberta Environment. Many municipal and industrial users were not licensed until the mid-1980s. Individual domestic users do not require a license, and not all licensed users are required to submit actual consumption numbers. Water licenses issued by Alberta Environment show the maximum amount of water that may be used, thereby giving an indication of what demands are being placed on the resource.

Table 8.1 shows that licensed production is nearly evenly split between surface water (6.5 million m^3/year) and groundwater (6.3 million m^3/year), as of March 2002. Between 1990 and 1995, groundwater licences increased from 4 million m^3 to 6 million m^3, while surface water licenses showed a similar increase between 1995 and 2000 (Figure 8.1). Water usage falls into three main categories: domestic use, whether by individual households, resorts, or municipalities; irrigation for golf courses or snow for ski hills; or industrial uses such as cooling, aggregate washing and dust control.

Surface water was accessed most often for industrial uses or for irrigation. Surface water withdrawals occur primarily in the Bow Valley, probably a result of concentration of industry and the availability of reliable flow from the Bow River. Groundwater is favoured primarily for municipal supply/domestic consumption, where potability is a concern because groundwater is naturally filtered and requires less treatment than surface water. Groundwater licences were fairly evenly split between the Bow Valley and Kananaskis regions. The Town of Canmore relies on a combination of surface water and groundwater for its municipal supply, but intends to transition entirely to groundwater. Seebe uses surface water, but would be using groundwater if sufficient amounts were available. All other communities rely entirely on groundwater. Ski hills are a major user of groundwater in the Kananaskis Valley, where groundwater is more dependable than surface water.

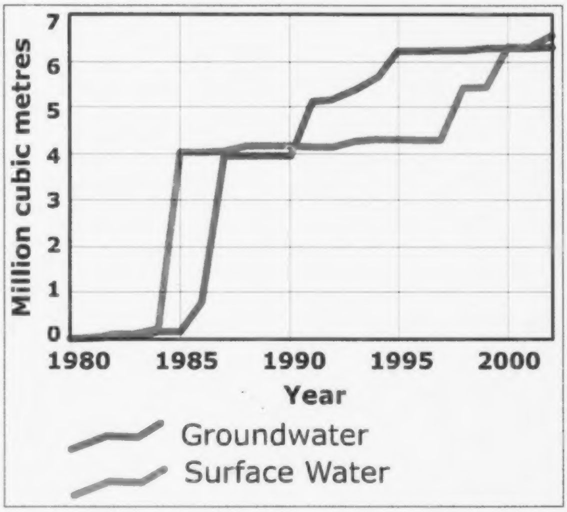


Figure 8.1 Surface and groundwater use in the Canmore region over the last two decades.

Apart from small losses to evaporation, the water used is returned to the system, so there is no significant net loss of water to the drainage basin; however, water may be redistributed on a local level, stressing vulnerable aquifers or altering timing and amount of surface flow. Although water is generally treated before it is released, it will not be pristine. Therefore, increased water consumption, combined with inadequate treatment, overload or leaching, may result in a deterioration of water quality.

Table 8.1 Types of water use in Bow Valley and Kananaskis.

Type of Use	Groundwater Licensed Diversion (m³/yr)				Surface Water Licensed Diversion (m³/yr)				All Licences (m³/yr)	
	Bow Valley	Kananaskis	Total	%	Bow Valley	Kananaskis	Total	%	Total	%
Campground or Group Camp	114,710	6,360	121,070	2	0	133,601	133,601	2	254,671	2
Domestic Group Supply	245,480	8,630	254,110	4	36,990	14,720	51,710	1	305,820	2
Golf Course	397,272	*0	397,272	6	1,540,570	259,140	1,799,710	28	2,196,982	17
Industrial	893,647	0	893,647	14	3,915,665	70	3,915,735	**60	4,809,382	38
Motels and Lodges	16,638	628,130	644,768	10	35,790	0	35,790	1	680,558	5
Ski Hills	0	2,763,000	2,763,000	44	0	191,190	191,190	3	2,954,190	23
Municipal	1,207,570	0	1,207,570	19	5,420	0	5,420	<1	1,212,990	9
Fisheries	0	0	0	0	5	402,117	402,122	6	402,122	3
Total	2,875,317	3,406,120	6,281,437	100	5,534,440	1,000,838	6,535,278	100	12,816,715	100

* Kananaskis Golf Course not differentiated from Kananaskis Village Supply
** Canmore surface water supply not distinguished from industrial

Limitations to development

The availability of a secure supply of potable water plays an important role in the type and scale of development an area can sustain; conversely, however, the scale of development may limit the long-term quantity and quality of water supply. Hydrogeological limitations on development in the Canmore Corridor were originally outlined by Ceroici and Prasad (1977).

Water quantity

The water quantity needed to supply a hand pump at a campground or single household is considerably less than a ranch, a resort or acreage development or an urban area. If the groundwater yield is insufficient for the scale of the development in question, there may be a need to access surface water supplies, or to locate a remote groundwater source and add a central distribution system. An alternative may be to limit the kinds of water use and the number of residents.

In the Bow Valley-Kananaskis region, difficulties finding water are most likely to occur where surficial aquifers are thin or drained, where there is a dependence on bedrock aquifers, or where population densities area high. Areas with limitations on yield include the Seebe district, the Knowlerville portion of Exshaw, and the southern ends of the Kananaskis and Spray valleys. Limitations occur at most locations outside of the valleys, but the mountainous areas are typically not developed because of the terrain. Exceptions are ski hills, alpine resorts and urban subdivisions of Canmore extending up the mountainsides.

Water quality

The *Guidelines for Canadian Drinking Water Quality* (2001), outline maximum allowable concentrations (MAC) and aesthetic objectives (AO) for a variety of constituents. Groundwater constituents may be naturally occurring or anthropogenic in origin, inorganic such as metal, organic such as pesticides or biological including bacteria and parasites. If any constituents exceed the MAC, then the water is unsuitable for human consumption. Parameters that exceed the AO may impart an unpalatable taste, or unpleasant characteristics such as staining or hardness without causing adverse health effects.

Groundwater quality in the Bow Valley-Kananaskis region is relatively high, compared to most of Alberta. (Refer to tables in Springs, Aquifers, and Appendix.) At a few sites, iron or hydrogen sulphide made water unpalatable. High iron was not noted in springs, only in wells, and is mostly related to well construction and maintenance. Hydrogen sulphide occurrence is rare, and was noted in three springs on the south side of the Bow Valley near Canmore, the WEPA deep test well at the Canmore tourist centre and a well in the Kananaskis Valley near Barrier Lake. Biological contamination is an issue not covered under the scope of this program, but is monitored by the Headwaters Health Unit.

Flow variations

In addition to water quality and quantity, limitations to development include slope stability, and a high or seasonally high water table.

Within the floodplain of the Bow River, and to a lesser extent the Kananaskis River, the water table is fairly shallow. The valleys are underlain by saturated, highly permeable sands and gravels, which are responsive to changes in river levels. The water table may fluctuate significantly on a seasonal basis particularly during spring runoff or after a major storm. The Kananaskis River and the Spray Lakes Reservoir have controlled discharge; water levels in valley aquifers may fluctuate with releases from those dams. Outside of the Town of Canmore, urban development along the floodplain is limited and groundwater flooding is not a major concern.

A seasonally high water table can flood foundations, basements and underground parking garages. The Town of Canmore experienced groundwater flooding in 1974. After that time a monitoring network was established to evaluate the effects of high water levels on the Town. This network has been recently upgraded in light of demands for development within the Town (AMEC, 2002).

Slope stability

Slope stability is affected by the lithology, structure and saturation of the slope. Clays tend to be less stable than sands and gravels. Bedrock that has been weakened by fracturing, jointing or dissolution is weaker and more prone to sliding. Groundwater influences slope stability by lubricating surfaces such as fracture planes. Saturation will raise the pore pressure between grains, weakening their cohesiveness.

The main erosive force in the mountains is frost wedging. Water that seeps into fractures then freezes will expand the crack, propagating the fracture front. An abundance of water may accelerate the process. Groundwater seeping out of rock face may weaken it at the surface.

Slope stability is most likely to be a consideration on the north-facing benchlands surrounding Canmore and, to a lesser degree, the south-facing benchlands, parts of the Kananaskis Valley and the Mount Shark region at the south end of the Spray Lakes Reservoir.

Protecting the water resource

Groundwater supports base flow to the Bow River and its tributaries by redistributing precipitation from higher elevations through the subsurface. Interaction between surface water and groundwater is pronounced, recognized both in the Marmot Creek basin study (Hydrocon, 1985) and in water table monitoring wells in Canmore (AMEC, 2002). What affects one will affect the other. As the headwaters to the Bow River basin, repercussions could be felt downstream to Calgary or beyond.

Mountainous areas, such as the Canmore Corridor and Kananaskis are particularly dependent on groundwater as a drinking water source, because groundwater does not require special treatment to remove water-borne parasites and flow is more reliable than with surface water. The aquifers in these areas, such as the Bow River aquifer are mostly unconfined, with little to buffer them from activities at the land surface and they tend to interact readily with surface water. The Calgary Buried Valley aquifer is more isolated from the land surface, protected along much of its length by a thick confining layer of clay. Beneath Canmore, and possibly the Many Springs area the confining layer between the buried valley aquifer and the Bow River aquifer is relatively thin and offers less protection. Bedrock aquifers depend mainly on faulting and fracturing for their permeability and may be vulnerable along such zones.

Groundwater plays a prominent role in Rocky Mountain water cycle that is largely overlooked. Disturbances or disruptions to the groundwater system, may affect the hydrogeology locally, farther down the flow system, or may alter the surface water regime. Groundwater-dependent aquatic ecosystems, such as spring-fed streams that are fish spawning areas, or pothole lakes where salamanders breed, are significant to the overall health of the environment. Springs gives rise to ecosystems that are home to rare or specialized flora and fauna, enhanced wildlife habitat or are significant cultural features. Changes to plant and animal communities dependent on site conditions created by groundwater may have farther-reaching effects on the environment. Recognition of the need for aquifer protection would be a significant step in managing the resource into the future.

Groundwater contamination

In the Bow Valley and Kananaskis regions, the surficial aquifers are typically unconfined and the substrate is highly permeable, making the aquifers vulnerable to contamination.

In recharge areas such as the benchlands, the groundwater table is relatively deep. Leachates may need to migrate considerable distances through the unsaturated zone, and depending on the nature of the leachate, the contaminants may evaporate, oxidize or otherwise break down before they reach the water table. Upon reaching the water table, however, they will disperse with flow into the saturated zone more rapidly than in discharge zones. In discharge areas, such as the floodplain of the Bow, Kananaskis and Spray Lakes valleys, the water table tends to be high, and contaminants will migrate relatively short distances to reach the saturated zone sooner. Within the saturated zone, contaminant migration will be curtailed by the upward component of groundwater flow.

Groundwater vulnerability to contamination is generally reduced where there is a thick, low-permeability confining layer above the aquifer that inhibits flow. Surficial aquifers are most vulnerable to contamination. Undesirable substances dispersed into the environment through human activity will eventually leach into the ground and to the water table unless broken down. Confined aquifers are considerably better protected than unconfined aquifers. They are vulnerable in their recharge areas or where the confining layer is breached through water or oil drilling and production or injection, or changes in stratigraphy.

Sources of groundwater contamination are diverse, but tend to be related human activities including urbanization and settlement, agriculture, industry and transport. Site-specific contamination is most commonly recognized, but diffuse loading over a wide area may also occur. Urban sources include domestic waste, household chemicals and particularly sewage. Agricultural sources generally come from the spreading of chemicals on fields, gardens, lawns and golf courses. Industrial sources may be related to improper handling of goods, or waste disposal. Transport includes pipeline breaks, chemical treatments along rail lines and road clearing salts. Contaminants may also originate from fallout of atmospheric pollution from distant sources.

Septic systems are the favoured option for treating household wastewater in rural areas, where communal sewage treatment facilities are unavailable. They require suitable site conditions on a sufficient land base, and they must be properly maintained so as not to be a risk to groundwater quality. Septic systems are used in the communities of Harvie Heights, Lac des Arcs and Seebe as well as by rural residents and park facilities.

Septic systems that are not functioning properly can act as sources of a variety of pollutants including phosphorus, nitrogen, organic matter, bacterial and viral pathogens, as well as any noxious substance dumped into the system. Conventional septic systems are not efficient at removing nitrogen, or inorganic ions. (Gordon, 1989; USEPA, 1993).

Nitrates, sodium and chloride at levels above background were noted in water samples from throughout the region. The levels were not dangerous, but they do indicate that septic systems are influencing water quality. Impacts were noted on scattered wells in Dead Man's Flats, Exshaw, Harvie Heights, Bow Valley Provincial Park and the Kananaskis Valley.

Wellhead protection

Despite due care and attention, accidents do occur, and releases of pollutants in populated areas is inevitable. Wellhead protection involves protecting a well's capture zone, which is a combination of the drawdown area together with the upstream portion of the groundwater flow field. It represents a fraction of the total aquifer. Should a spill occur, attempts may be made to intercept and remove the pollutant before it reaches the town production wells. The Town of Canmore has its main water supply wells near the Rundle Power Plant and the backup wells adjacent to Policeman's Creek near Railway Avenue and Bow Valley Trail. The wells are less than 30 m deep in an unconfined aquifer with a high water table. Canmore has initiated a wellhead protection program in cooperation with Alberta Environment to protect the capture zone from spills that could contaminate the aquifer.

Hydrogeological preserves

A commonly overlooked mechanism for aquifer protection is a hydrogeological preserve (de Marsily, 1992). Watersheds for reservoirs that supply drinking water are sometimes designated protected areas and activities that could endanger the water supply are restricted (e.g., Sooke Reservoir for greater Victoria, B.C.); however, groundwater traditionally has not received the same recognition. Significant portions of the Canmore Corridor and Kananaskis Country are set aside to protect the natural environment as a whole and, in doing so, they offer protection to the region's aquifers. For example, significant stretches of the Bow River aquifer lie within the Bow Flats portion of the Bow Valley Wildland Park. However, the preservation of groundwater should be actively recognized as a component, rather than a by-product, of environmental protection.

Summary and recommendations

We undertook this study in recognition of the need to protect the integrity of the groundwater resource in the Canmore Corridor and Northwest Kananaskis Country, a region significant for its natural environment positioned in the front ranges of the Rockies, its location in headwaters of the Bow River, and as a region experiencing pressures of economic growth and development.

Groundwater is the primary source of drinking water in the region. Canmore, the major community of the Bow Valley uses a central supply system that is more reliable than the individual domestic wells used in neighbouring hamlets of Harvie Heights, Exshaw, Dead Man's Flats and Lac des Arcs, and private wells of industry, resorts, campgrounds and ranches. Nearly all wells are completed in surficial sands and gravels initially laid down by glaciers. These sands and gravels drape the mountainsides and line the valley bottoms forming the region's aquifers, usually 30 to 100 m thick, but in parts of the Bow Valley aquifer fill may extend beyond 200 m. Groundwater yields are typically good in the valley bottoms, usually exceeding of 100 litres per minute, but may be limited along the mountainsides where the water table is low, or in the valley where drift cover is thin. In most places sufficient water supplies can be found within 30 m of surface.

Water quality in general is good, and under most circumstances is within the limits set by *Guidelines for Canadian Drinking Water Quality*. Wells occasionally report excessive iron, total dissolved solids, or in rare cases, hydrogen sulphide odour. Poorer quality water is often associated with bedrock. The water type is most commonly calcium-magnesium-bicarbonate-sulphate, similar to that of the Bow River, less often calcium-magnesium-bicarbonate or calcium-magnesium-sulphate-bicarbonate. Variations in water types are sometimes attributable to local variations in geology.

High topographic relief accentuates gravity-driven groundwater flow and subsequent recharge and discharge conditions. Isotopic analysis indicates that most groundwater originates locally from the mountainsides. Springs are common in the valley bottoms and are used by people and wildlife. An overlooked aspect of groundwater is its role in sustaining ecosystems. The redistribution of moisture, nutrients and heat by groundwater flow influences the development of plant communities and consequently the distribution of animal life, particularly significant to the drier Montane ecoregion.

Groundwater usage has increased with the region's development and growing population. Demand for water is concentrated around population centres and not necessarily where supplies are greatest. Care should be taken to ensure that all residents of the valley have reliable access to water supply.

Because of its ready interaction with the land surface, the groundwater is vulnerable to contamination. Situated in the headwaters of the Bow River, impacts on groundwater in the Canmore Corridor and Kananaskis will be felt locally and potentially downstream. Precautions and emergency planning should be in place to prevent pollutants from entering the groundwater system. Individual projects may have minimal impacts, but the cumulate effects of paving, excavating, water withdrawals and chemical loading all have the long term potential to alter groundwater conditions and the region's ecology.

Groundwater has played a role in the history, ecology and economic growth of the region. Proper stewardship is necessary so that a clean secure groundwater supply and the natural environment it sustains are available to future generations of Albertans. To safeguard the integrity of the groundwater, we recommend the establishment of hydrogeological preserves, which should be actively recognized as a vital component, rather than a by-product, of environmental protection. We also recommend that emergency groundwater protection plans be devised and followed in the event of a contaminant spill.

We recommend continued study of the groundwater resources of the Canmore Corridor and Northwestern Kananaskis Country to understand the vulnerability of aquifers to depletion and their potential response to natural and engineered changes in surface water discharge. Monitoring of the areas's aquifers—through Alberta Environment's groundwater monitoring well network—should help show the relationship between the water table and surface water levels. We also recommend further investigation to determine the extent and productivity of aquifers (particularly the buried valley aquifer), through exploratory drilling, well monitoring, pump testing and water quality sampling.

References

Appleby, Edna, 1975. Canmore: The Story of an Era. Edna Appleby, Friesen and Sons Ltd. printer, Calgary, Alberta. 163pp.

Alberta Environment, 1982. South Saskatchewan River Basin Historical Natural Flows: 1912-1978. J.R Card, F.D. Davies, R. A. Bothe, Hydrology Branch. Alberta Environment, Edmonton, Alberta.

Alberta Environment, 1985. *Alberta Watershed Research Program: Hydrometeorological Research.* Alberta Environment, Edmonton, Alberta.57pp.

Alberta Environment, 1999. *Yamnuska Natural Area Interim Management Plan.* Alberta Env., Edmonton, Alberta.

Alberta Environmental Protection, 1997a. *Canmore Flats Natural Area Management Plan,* AEP, Edmonton, Alberta.

Alberta Environmental Protection, 1997b. *Wind Valley Natural Area Management Plan,* AEP, Edmonton, Alberta.

Alberta Forestry Lands & Wildlife, 1990. *Bow Corridor Local Integrated Resource Plan.* Alberta Forestry, Lands and Wildlife, Pub No. I/301. Calgary, Alberta.

Alberta Forestry Lands & Wildlife, 1992. *Bow Corridor Local Integrated Resource Plan.* Alberta Forestry, Lands and Wildlife, Calgary, Alberta.

AMEC Earth and Environmental Limited, 2002. *Installation of a Piezometer Network and Development of a Groundwater Level Model.* For: Town of Canmore. AMEC Earth and Environmental Limited, Calgary, Alberta.

Archibald, J.H., G.D. Klappstein and I.G.W. Corns, 1996. *Field Guide to Ecosites of Southwestern Alberta.* Canadian Forest Service, Northern Forestry Centre, Special Report #8, UBC Press, Vancouver, British Columbia.

Beak Associates Ltd., 1986. *Lac des Arcs fish and waterfowl study.* For: Improvement District #8, Alberta Municipal Affairs, Canmore, Alberta.

Beke, G.J. 1969. *Soils of three experimental watersheds in Alberta and their Hydrologic Significance*". Unpublished Ph.D. thesis, University of Alberta, Edmonton, Alberta.

Borneuf, D. 1983. *Springs of Alberta.* Alberta Research Council Earth Sciences Report #82-3. Edmonton, Alberta.

Ceroici, W.J. 1977. *Hydrogeological Limitations to Land Development in the Canmore Corridor, Alberta.* Groundwater Division, Alberta Research Council, Edmonton, Alberta.

Ceroici, W.J. and B.S. Prasad, 1977. *Hydrogeology of the Canmore Corridor, Alberta.* Alberta Research Council, Edmonton, Alberta.

Craig, H. and L.I. Gordon, 1965. *Deuterium and oxygen-18 variations in the ocean and marine atmosphere.* In: Stable Isotopes in Oceanographic Studies, E. Tongiorgi, Ed. Cosiglio Nazionale del Richerche, Laboratorio di Geologia Nucleare, Pisa, Italy.

Daffern, Gillean, 1994. *Canmore and Kananaskis Country: Short Walks for Inquiring Minds #1.* Rocky Mountain Books, Calgary, Alberta. 296 pp.

Dawson, T.E. and J.R. Ehleringer, 1991. Streamside trees that do not use stream water. Nature, 350: 335-337.

Davis, D.A., 1964. *Collection and Compilation of Streamflow data in Marmot Creek Basin*, Proceedings of Hydrology Symposium Data in "Research Watersheds", National Research Council of Canada, Ottawa, 105-116.

de Marsily, G. 1992. Creation of "Hydrogeological Nature Reserves": a plea for the defence of groundwater. *Ground Water* 30(5): 658-659.

Dowling, D.B. 1907. *Report on the Cascade Coal Basin, Alberta*. Geological Survey of Canada Pub. 949, Ottawa, Ontario

Edwards, W.A.D., 1979. *Sand and Gravel Deposits in the Canmore Corridor Area, Alberta*. Alberta Research Council Earth Sciences Report 79-2, Edmonton, Alberta. 30pp.

Edwards, W.A.D., 1991. *Geology and Industrial Minerals of the Bow Valley Banff-Canmore Area, Alberta: 27th Forum on the Geology of Industrial Minerals Field Trip 1A*. Alberta Geological Survey, Edmonton. Alberta 45 pp.

Farvolden, R.N., 1961. *Groundwater Resources, Pembina area, Alberta*. Research Council of Alberta Report 61-4. Edmonton, Alberta.

Golding, D.L. 1969. *Snow Relationships in the Marmot Creek Experimental Watershed*. Canadian Department of Fisheries and Forestry, Bimonthly Research Notes, 25-2, 12-13.

Grasby, S.E. 2002. *Bow Valley Canmore – Kananaskis Groundwater Mapping Program: Stable Isotope Interpretation (2002)*. Geological Survey of Canada For: Alberta Environment Hydrogeology Section. Edmonton, Alberta.

Grasby, S.E. 2001. Hot and Cold Running Water in the Canadian Rockies: The influence of fault plane geometry on spring temperatures. 2nd National Conference on Groundwater Field Trip Notes, September 22, 2001. Geological Survey of Canada, Calgary, Alberta.

Grasby, S.E. and I. Hutcheon 2001. *Controls on the distribution of thermal springs in southern Alberta and British Columbia*. Canadian Journal of Earth Sciences, 38, 427-440.

Green, J.C. Pacas, L. Cornwell and S. Bayley (eds), 1996. *Ecological Outlooks Project. A Cumulative Effects Assessment and Futures Outlook of the Banff Bow Valley*. for the Banff Bow Valley Study. Dept. of Canadian Heritage, Ottawa, Ontario.

GTS Group International, 1997. *The Bow Corridor Rock Industry: Contribution to the Alberta regional economy*. for: Alberta Economic Development, Edmonton, Alberta. 17pp.

Hamilton, W.N., M.C. Price and D.K. Chao, 1998a. *Geology of the Bow Corridor*. Alberta Geological Survey Map 232A, Edmonton, Alberta.

Hamilton, W.N., M.C. Price and D.K. Chao, 1998b. *Mineral Deposits of the Bow Corridor*. Alberta Geological Survey Map 232B, Edmonton, Alberta.

Hamilton, W.N., M.C. Price and D.K. Chao, 1998c. *Mineral Deposits and Prospective Areas in the Bow Corridor*. Alberta Geological Survey Map 232c, Edmonton, Alberta.

Hawes, R.J., 1977. *The Glacial Geomorphology of the Kananaskis Valley, Rocky Mountain Front Ranges, Southern Alberta*. University of Calgary, Department of Geography, Unpublished Masters Thesis, Calgary, Alberta. 204 pp.

Hayashi, M. and D.O. Rosenberry, 2001. *Effects of groundwater exchange on the hydrology and ecology of surface waters*. Journal of Groundwater Hydrology 34:327-341. Published by Japanese Association of Groundwater Hydrology.

Health Canada, 2001. *Guidelines for Canadian Drinking Water Quality*. Supply and Services Canada, Ottawa, Ontario.

Hewlett, J.D. and A.R. Hibbert, 1967. *Factors affecting the response of watershed to precipitation in humid areas*. In: proceedings of International Symposium for Hydrology, W.E. Sopper and H.W. Ledd eds. Pergamon Press, Oxford, United Kingdom.

Holland and Coen, 1992. *Ecological (biophysical) Land Classification of Banff and Jasper National Parks*. Volume III: The Wildlife Inventory. Canadian Wildlife Services report to Parks Canada, Calgary, Alberta.

Hydrogeological Consultants Ltd. 1978. *Kananaskis Country 1978 Groundwater Development Program*. Kananaskis Country Utility Study. Edmonton, Alberta.

Hydrogeological Consultants Ltd. 1981. *Alberta Fish and Wildlife Many Springs 1981 Groundwater Evaluation Program*. Edmonton, Alberta

Hydrocon Engineering Ltd., 1985. *Marmot Creek Experimental Watershed Study*. Prepared for: the Water Survey of Canada, Calgary, Alberta. 52pp.

Jackson, L.E. Jr. 1987. *Terrain Inventory of the Kananaskis Lakes Map Area, Alberta*. Geological Survey of Canada Paper 86-2, Ottawa, Ontario.40 pp.

Kirby, C.L. and R.T. Ogilvie, 1969. *The Forests of Marmot Creek Watershed Research Basin*. Canadian Forest Service, Ottawa, Ontario.

Klijn, F. and J.M. Witte, 1999. Eco-hydrology: Groundwater flow and site factors in plant ecology. *Hydrogeology Journal*. 7 (8): 65-77.

Leskiw, L.A., 1971. *Relationship between soils and groundwater in field mapping near Vegreville, Alberta*. MSc. University of Alberta, Edmonton, Alberta.

Longley, R.W., 1972. *The Climate of the Prairie Provinces*. Environment Canada, Atmospheric Environment, Climatological Studies 13, Toronto, Ontario. 79p.

Longmore, L.A. and C. E. Stenton, 1981. *The Fish and Fisheries of the South Saskatchewan River Basin: Their Status and Environmental Requirements*. Alberta Fish and Wildlife, Edmonton, Alberta.

McGregor, C.A., 1984. *Ecological Land Classification and Evaluation: Kananaskis Country, Vol. I, Natural Resource Summary*. AB Energy & Natural Res., Edmonton, Alberta.

Monenco Consultants Limited, 1980a. *Kananaskis Country Trout Rearing Facility: Water Monitoring at Exshaw and Bow Springs*. For: Department of Energy and Natural Resources Fish and Wildlife Division. Calgary, Alberta.

Monenco Consultants Limited, 1980b. *Kananaskis Country Trout Rearing Facility: Additional Investigation at Bow Springs.* For: Department of Energy and Natural Resources Fish and Wildlife Division. Calgary, Alberta.

Monenco Consultants Limited, 1980c. *Kananaskis Country Trout Rearing Facility: Volume 1: Feasibility of Ground and Surface Water Supplies.* For: Department of Energy and Natural Resources Fish and Wildlife Division. Calgary, Alberta.

O'Leary, D.J., 1988. *Integrated Resource Inventory and Evaluations of the Bow Corridor Integrated Resource Planning Area.* Alberta Forestry, Lands and Wildlife. Pub No. T/184 Edmonton, Alberta.

Ollerenshaw, N.C., 1975, *GSC Map 1457A: Calgary, west of Fifth Meridian, Alberta-British Columbia.* Scale !:250,000. Ottawa, Ontario.

Ozoray, G., 1977. *Apparent Transmissivity and determination by nomgram.* In: Alberta Research Council Bulletin 35, Edmonton, Alberta.

Pacas, C., D. Bernard, N. Marshall & J. Green, 1996. *State of the Banff-Bow Valley Rept.* Compiled by C. Pacas & J. Green, Banff Bow Valley Study, Banff, Alberta, D. Bernard, ESSA Technologies Ltd., Vancouver, B.C., N. Marshall, Praxis Inc., Calgary, Alberta.

Parliament of Canada, 1947. An act respecting the protection and conservation of the forests on the Eastern Slope of the Rocky Mountains, Ottawa, Ontario.

Peterjohn, W.T. and D.L. Correll, 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology, 65: 1466-1475.

Reid, Crowther and Partners Ltd. 1979. *Kananaskis Country Utility Study Summary Report.* Calgary, Alberta.

RGI Ltd. 1999. *Kananaskis.* Resource GIS and Imaging, Vancouver, B.C. Image based on 1996 IRS data.

Rutter, N.W., 1972. *Geomorphology and multiple glaciation in the area of Banff, Alberta, Canada.* Department of Energy, Mines and Resources, Ottawa, Ontario.

Scheelar, M.D. 1976. Detailed soil survey of the Canmore corridor area. Alberta Institute of Pedology (Series) M-76-13, Edmonton, Alberta.

Skolvin, J.M., 1982. *Habitat requirements and evaluations. in: Elk of North America: Ecology and Management.* Thomas, J.W. & D.E. Toweill, eds. Wildlife Management Institute & Stackpole Books. Washington D.C.

Stalker, A.M. 1973. Surficial Geology of the Kananaskis Research Forest and Marmot Creek Basin Area, Alberta. Geological Survey of Canada Paper 72-51, Ottawa, Ontario 25 pp.

Stevenson, Douglas Roy, 1967. *Geological and Groundwater Investigations in the Marmot Creek Experimental Basin of Southwestern Alberta, Canada.* University of Alberta, Unpublished master's thesis, Edmonton, Alberta 56pp.

Stevenson, D.R. 1971. *Collection and Compilation of Groundwater Data in the Marmot Creek Experimental Basin.* Research Council of Alberta Open File Report 1971-11, Edmonton, Alberta 31pp.

Storr, D. 1967. *Precipitation Variations in a Small Forested Watershed.* Proceedings, 35th Western Snow Conference.

Storr, D. 1974. *Relating Sub-Surface Water Storage to Streamflow in a Mountainous Watershed.* Canadian Meteorological Research Report 4-74. Environment Canada, Downsview, Ontario.

Storr, D. 1977. *Some Preliminary Water Balances of Marmot Creek Subbasins.* in: Alberta Watershed Research, Progress Symposium Proceedings, Swanson and Logan editors, Canadian Forest Service, Edmonton, Alberta. Rept. NOR-X-176, pp 159-177.

Strong, W.L. 1992. *Ecoregions & Ecodistricts of Alberta.* AB Forestry Lands & Wildlife, Pub. T/244, Edmonton, Alberta.

Swanson, R.H & D.L. Golding, 1982. *Snowpack Management on Marmot Creek Watershed to Increase Late Season Streamflow.* Western Snow Conference Proceedings, Reno, Nevada. pp 215-218.

Swanson, R.H., D.L Golding, R.L. Rothwell, P.Y. Bernier, 1986. *Hydrologic Effects of Clear-cutting at Marmot Creek and Streeter Watersheds, Alberta.* Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Inf. Rept. NOR-X.

Sweetgrass Consultants Limited, 1991. *Environmentally Significant Areas in the Bow River Corridor.* For: Municipal District of Bighorn, Exshaw, Alberta.

Timoney, K.P., 1991. *Biophysical Inventory of the Canmore Flats Natural Area.* Alberta Forestry, Lands and Wildlife, Ref no. 685-821, Edmonton, Alberta.

Tóth, J., 1962. A theory of groundwater motion in small drainage basins in central Alberta, Canada. *J. of Geoph. Res.*, 67 (11): 4375-4387

Tóth, J., 1963. A theoretical analysis of groundwater flow in small drainage basins: *J Geoph. Res.*, 68 (16): 4795-4812

Tóth, J., 1966. Mapping and interpretation of field phenomena for groundwater reconnaissance in a prairie environment, Alberta, Canada. *Bull. Intern. Assoc. Sci. Hydro.*, 11 (2):1-49.

Tóth, J., 1971. Groundwater discharge: A common generator of diverse geologic and morphologic phenomena. *Bull Intern. Assoc. Sci Hydro.*, 16(1-3): 7-24

Tóth, J., 1972. Properties and manifestations of regional groundwater movement. *Proceedings 24th International Geologic Congress* Section 11, Montreal: 153-163

Tóth, J., 1999. Groundwater as a geologic agent: An overview of the causes, processes and manifestations, *Hydrogeology Journal*, 7 (1):1-14

Tóth, J., and R.F. Millar, 1983. Possible effects of erosional changes of the topographic relief on pore pressures at depth. Water Resources Research, 19: 1585-1597.

University of Calgary, 1994. *The Wind Valley: A Proposal for an Ecological Reserve*, University of Calgary Faculty of Env. Design for Town of Canmore, Calgary, Alberta.

Van Everdingen, R.O., 1972. *Thermal and mineral springs in the southern Rocky Mountains of Canada.* Department of Environment , Water Management Service, Ottawa, Ontario.

Van Tighem, K., 1993. Heart of a Mountain Ecosystem. *Environmental Views*, Alberta Environmental Protection, Edmonton, Alberta. 16, (2): 3-7.

Water Survey of Canada, 1980. *Compilation of Hydrometeorological Record, Marmot Creek Basin 1980 Data, Volume 16*. Canada Department of the Environment, Calgary District. 91 pp.

Westworth, D.A., L.M. Brusnyk & G.R. Burns, 1984. *Impact on wildlife of short-rotation management of boreal aspen stands*. Westworth & Associates Ltd. Edmonton, Alberta.

Woods, J., 1991. *Ecology of a partially migratory elk population*. PhD. Thesis, U. of British Columbia, Vancouver.

Yonge, C.J. 2000. *Bow Valley Canmore – Kananaskis Groundwater Mapping Program: Stable Isotope Interpretation (2000)*. Alberta Karst Consulting, For: Alberta Environment Hydrogeology Section. Edmonton, Alberta.

Yonge, C.J. 2001. *Bow Valley Canmore – Kananaskis Groundwater Mapping Program: Stable Isotope Interpretation (2001)*. Alberta Karst Consulting, For: Alberta Environment Hydrogeology Section. Edmonton, Alberta.

Yonge, C. and H.R. Krouse, in prep. *Isotope composition of precipitation and its relation to weather systems at Calgary, Alberta, Canada*.

Acknowledgements

The *Hydrogeology of the Canmore Corridor and Northwestern Kananaskis Country* was a study undertaken by Alberta Environment, Hydrogeology Section. This project was funded by the Canada-Alberta Western Economic Partnership Agreement (WEPA), a joint initiative between Western Economic Diversification Canada and Alberta Environment. The agreement demonstrates cooperation and commitment between federal and provincial governments for building a sound economy and environmentally sustainable future for Albertans, and for all Canadians who share our natural heritage.

We would like to thank the residents—homeowners, ranchers and business people—of the Canmore Corridor and Northwestern Kananaskis Country, whose warm hospitality and enthusiastic cooperation made the project a reality. Local facilities, expertise and inspiration were provided courtesy of the Canmore office of Alberta Environment, Parks and Protected Areas and Bow Valley Park interpreters, the Municipal District of Bighorn, the Town of Canmore and Bow Valley Campgrounds.

Drilling services were provided by Alken Basin Drilling and by Aaron Drilling Limited. Land access was granted by Alberta Public Lands, the M.D. of Bighorn, the Town of Canmore, Rafter Six Ranch and LaFarge Canada. Water analysis services were provided by Maxxam Analytical, and by the University of Calgary, Department of Physics, and the aerial survey by Alpine Helicopters Limited.

Project Manager - Nga de la Cruz

Written by - David Toop

Reviewed by -
Nga de la Cruz, Glenn Winner

Layout - Frank Geddes

Administration -
Ron Bothe, Brenda Emmel, Angie Estephan, Cal Webb, David May

Field Program and Well Survey -
Adam Benn, Jesse Peterson, David Toop

Field Assistance -
Steven Clare, Lisa Mazuryk, Kevin Nipp, Glenn Winner

Computer Mapping - Kevin Nipp

Cross Sections and Logs - Jesse Peterson

Hydrochemistry Graphs - David Toop

Groundwater Database - Gary Blechinger

Groundwater Model - Mafiz Uddin

Stable Isotope Interpretation -
Charles Yonge, Stephen Grasby

Figures and Photographs - David Toop

Additional photos - Nga de la Cruz

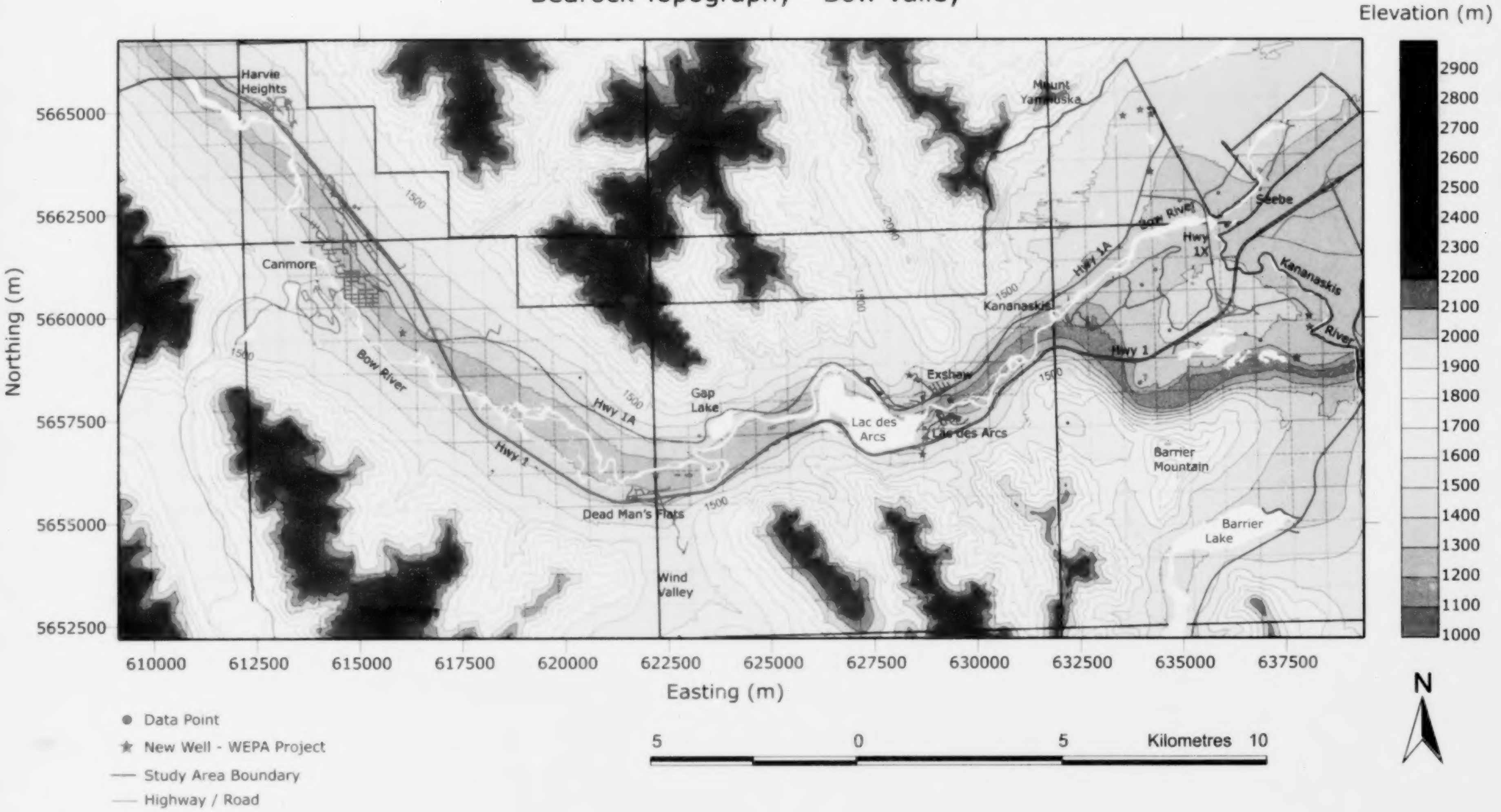
Cover Photo Image of Kananaskis -
RGI Limited of Vancouver

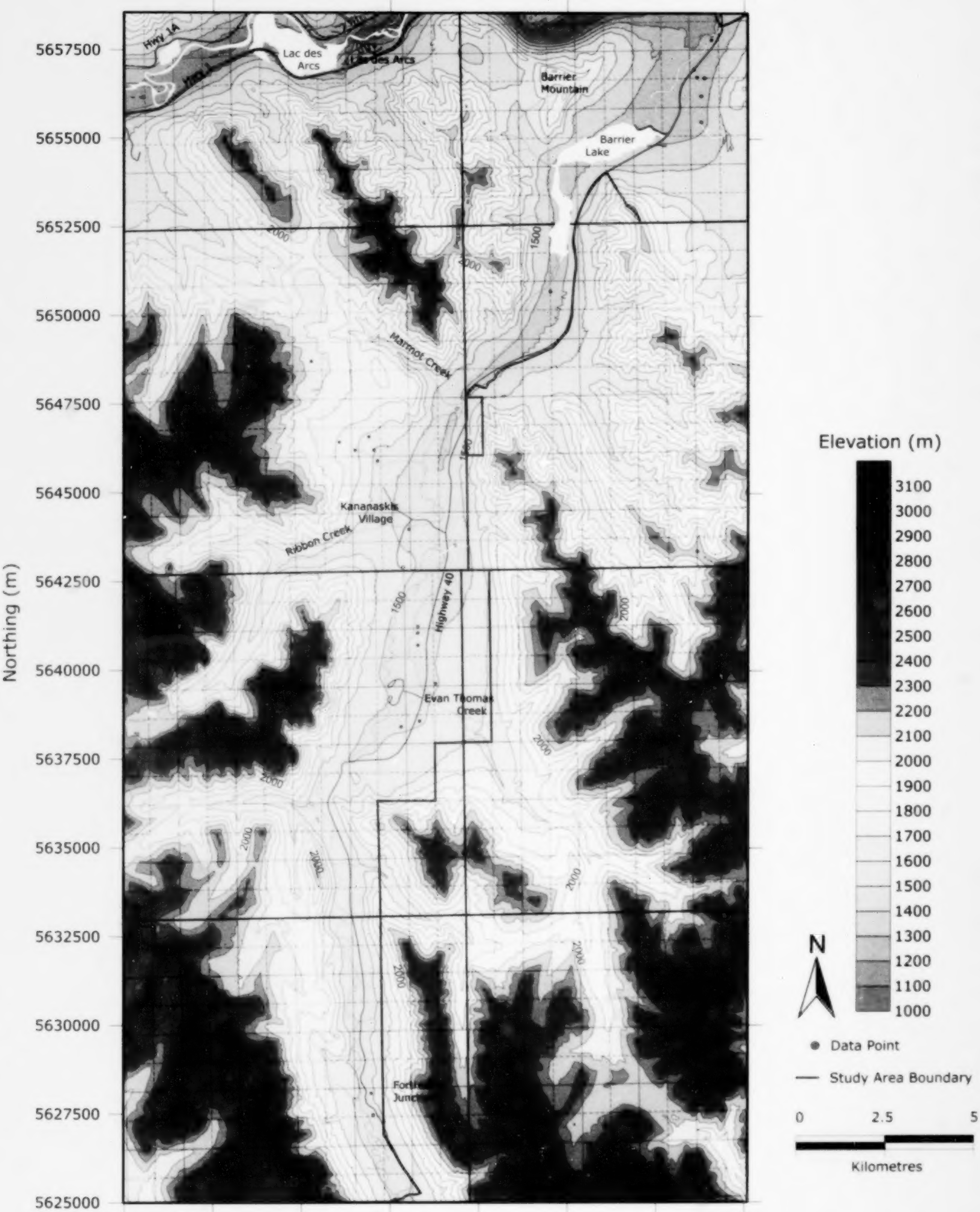
Appendix A

Hydrogeological Maps

Bedrock Topography – Bow Valley
Bedrock Topography – Kananaskis Valley
Bedrock Topography – Spray Lakes Valley
Drift Thickness – Bow Valley
Drift Thickness – Kananaskis Valley
Drift Thickness – Spray Lakes Valley
Yield Zones – Upper Drift Aquifer – Bow Valley
Yield Zones – Kananaskis Valley
Yield Zones – Spray Lakes Valley
Hydraulic Head – Bow Valley
Hydraulic Head – Kananaskis Valley
Bedrock Geology

Bedrock Topography - Bow Valley

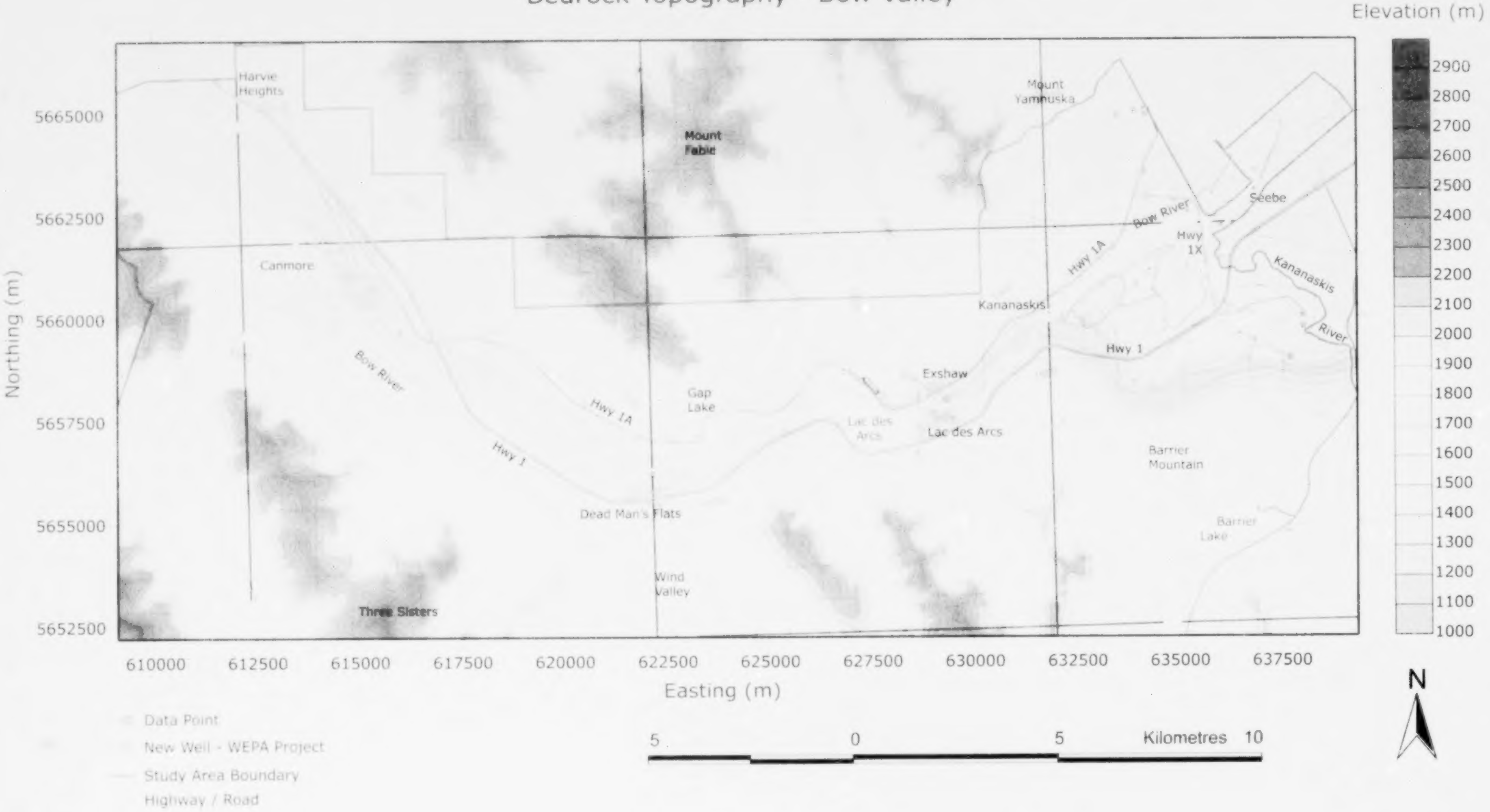

Elevation (m)
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Harvie Heights
Canmore
Bow River
Hwy 1A
Hwy 1
Dead Man's Flats
Wind Valley
Gap Lake
Lac des Arcs
Exshaw
Kananaskis
Mount Yamnuska
Bow River
Hwy 1X
Seebe
Kananaskis River
Barrier Mountain
Barrier Lake
1500
2000
N
5
0
5
Kilometres 10
Data Point
New Well - WEPA Project
Study Area Boundary
Highway / Road



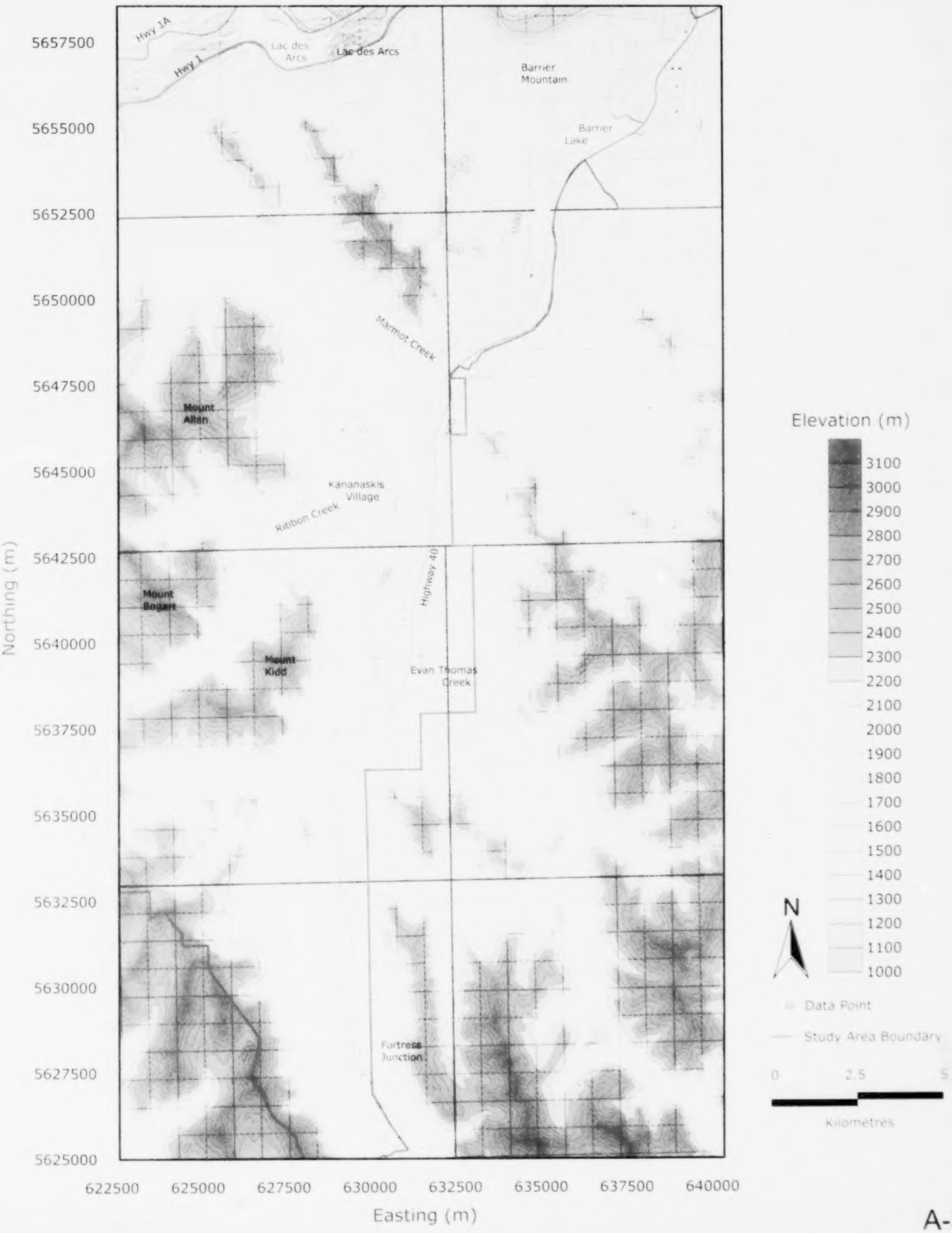
Bedrock Topography - Kananaskis Valley

Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Mountain
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
1500
2000
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
Elevation (m)
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
N
● Data Point
— Study Area Boundary
0
2.5
5
Kilometres

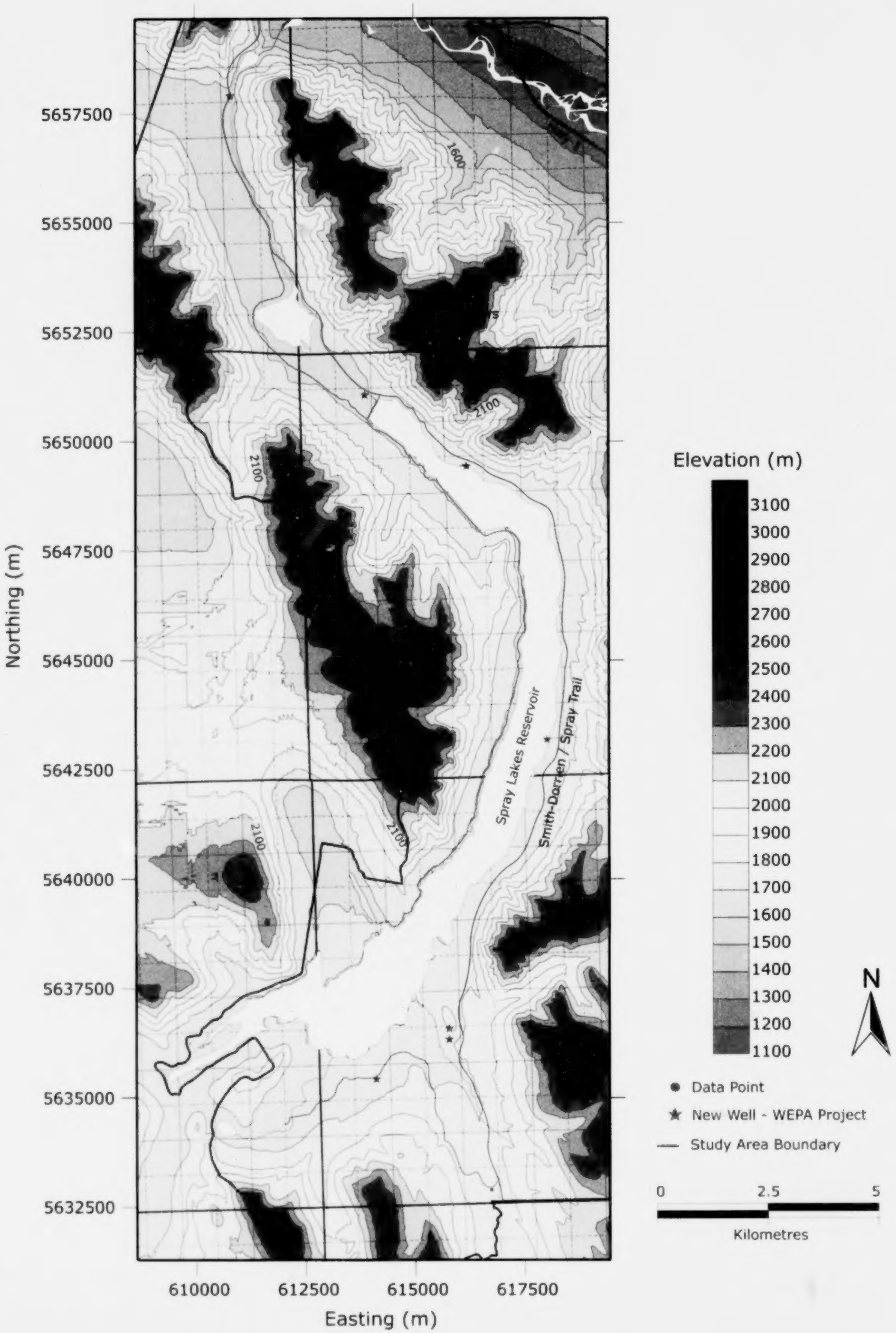
Bedrock Topography - Bow Valley


Elevation (m)
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Harvie Heights
Canmore
Bow River
Mount Fable
Three Sisters
Hwy 1A
Hwy 1
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Exshaw
Lac des Arcs
Kananaskis
Mount Yamnuska
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis
River
Hwy 1
Barrier Mountain
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Easting (m)
Data Point
New Well - WEPA Project
Study Area Boundary
Highway / Road
5
0
5
Kilometres
10
N

Bedrock Topography - Kananaskis Valley

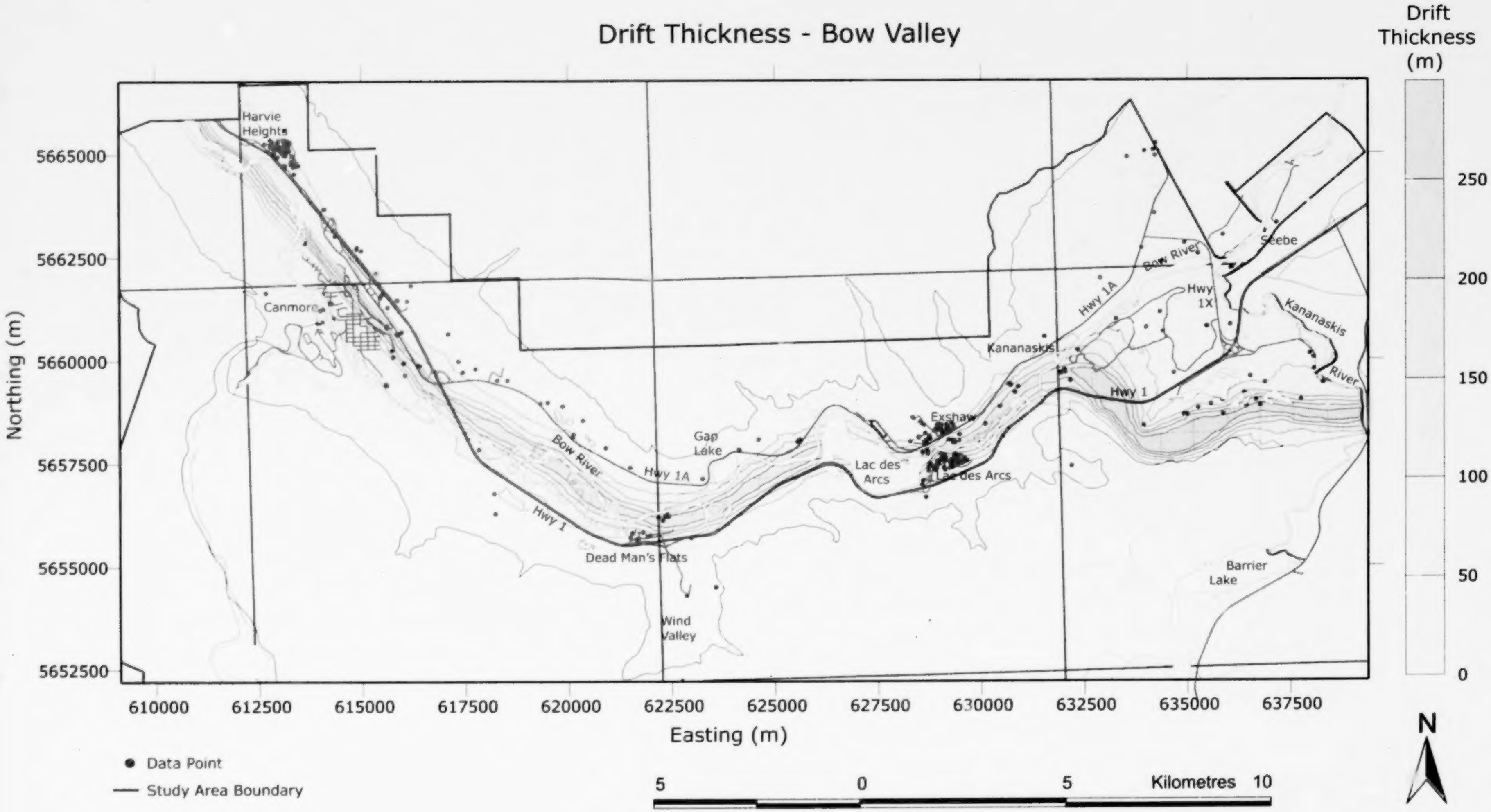

Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Mountain
Barrier Lake
Marmot Creek
Mount Allan
Kananaskis Village
Ribbon Creek
Highway 40
Mount Bogart
Mount Kidd
Evan Thomas Creek
Fortress Junction
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Northing (m)
622500
625000
627500
630000
632500
635000
637500
640000
Easting (m)
Elevation (m)
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
N
Data Point
Study Area Boundary
0
2.5
5
Kilometres

Bedrock Topography - Spray Lakes Valley

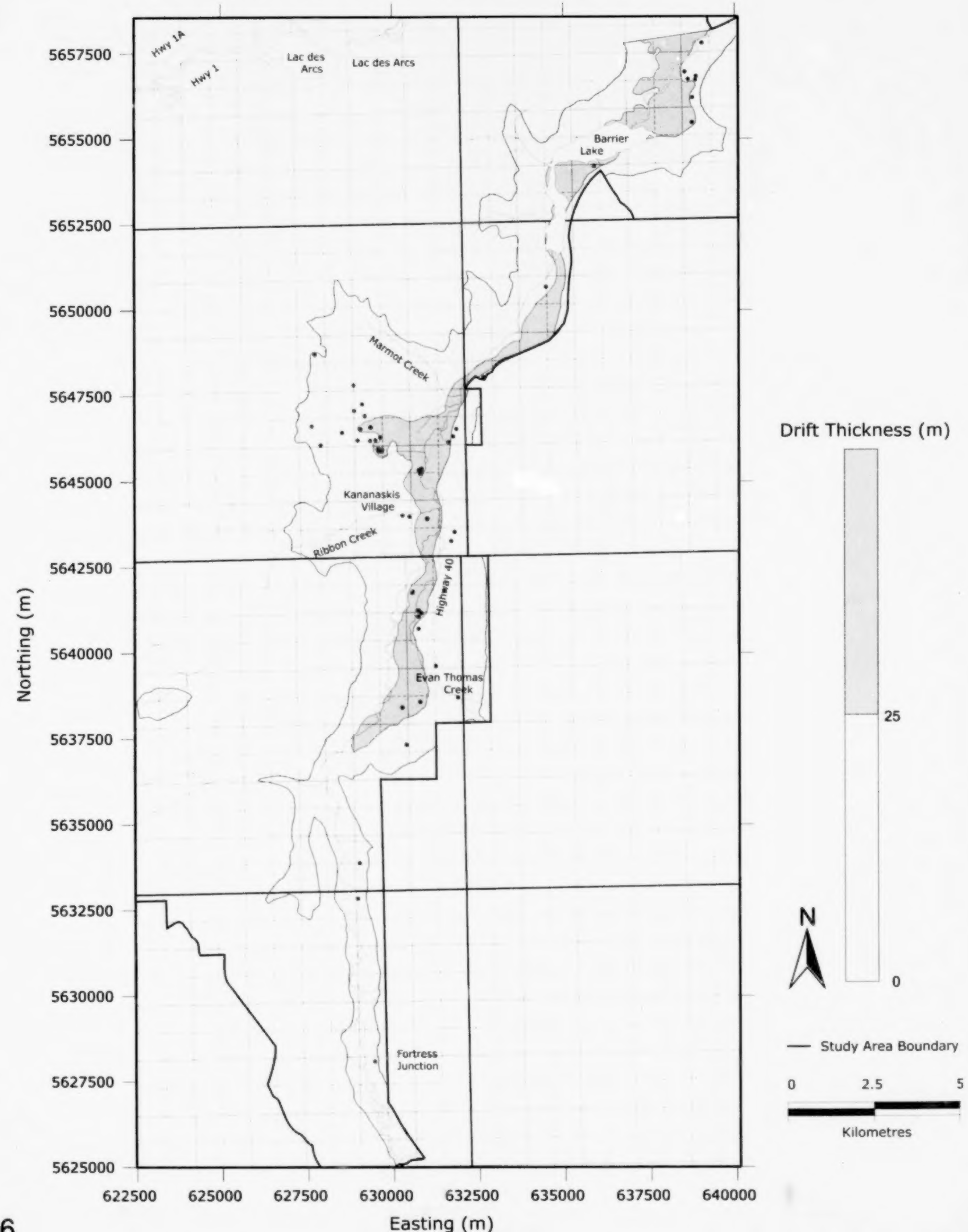


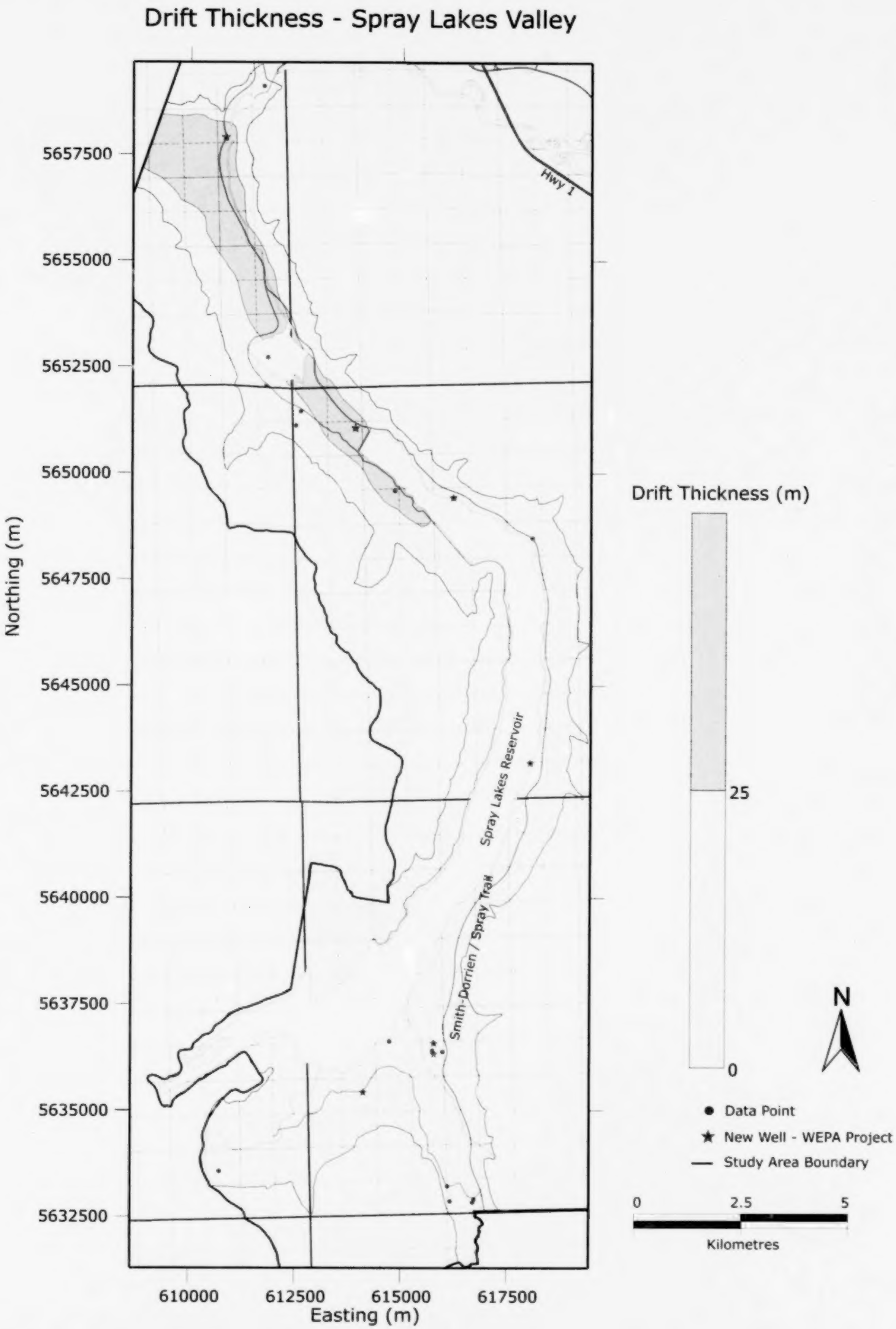
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Easting (m)
610000
612500
615000
617500
1600
2100
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
Elevation (m)
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
N
● Data Point
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

Drift Thickness - Bow Valley

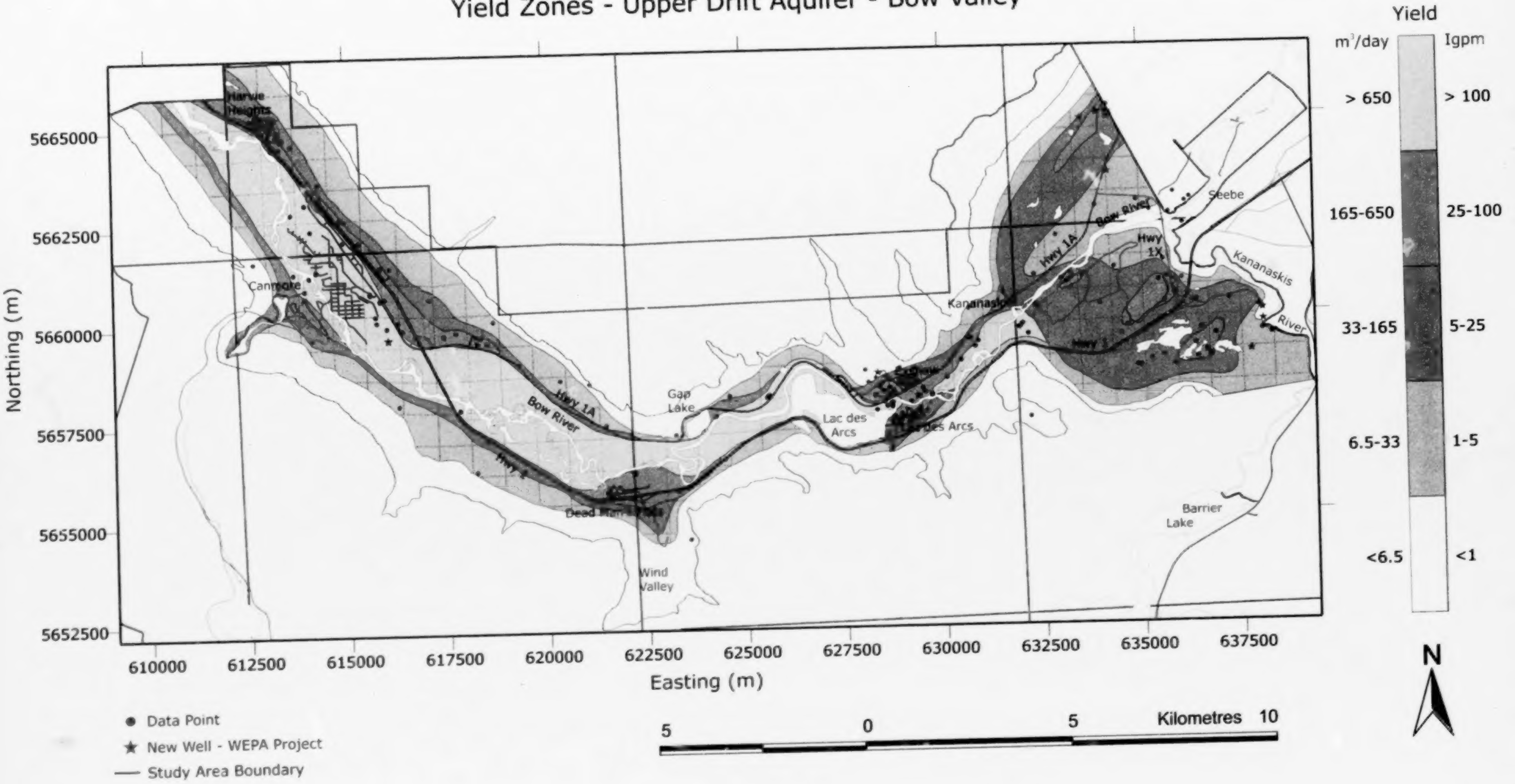

Drift Thickness (m)
250
200
150
100
50
0
Harvie Heights
Canmore
Bow River
Hwy 1
Hwy 1A
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Exshaw
Lac des Arcs
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Hwy 1
Seebe
Kananaskis River
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Easting (m)
● Data Point
— Study Area Boundary
5
0
5
Kilometres 10
N

Drift Thickness - Kananaskis Valley

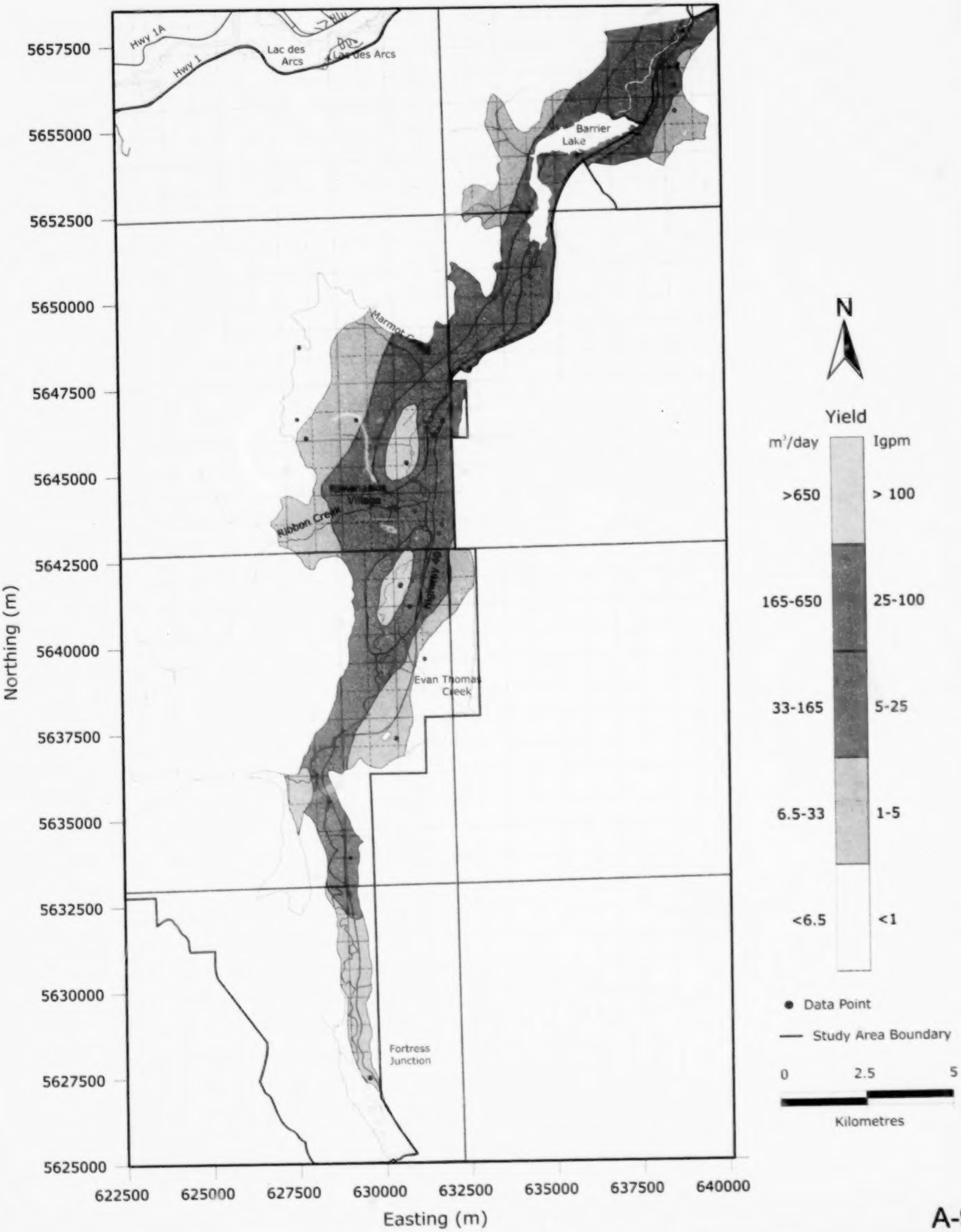

Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
Drift Thickness (m)
25
0
N
Study Area Boundary
0
2.5
5
Kilometres


Drift Thickness - Spray Lakes Valley
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Easting (m)
610000
612500
615000
617500
Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
Drift Thickness (m)
25
0
N
● Data Point
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

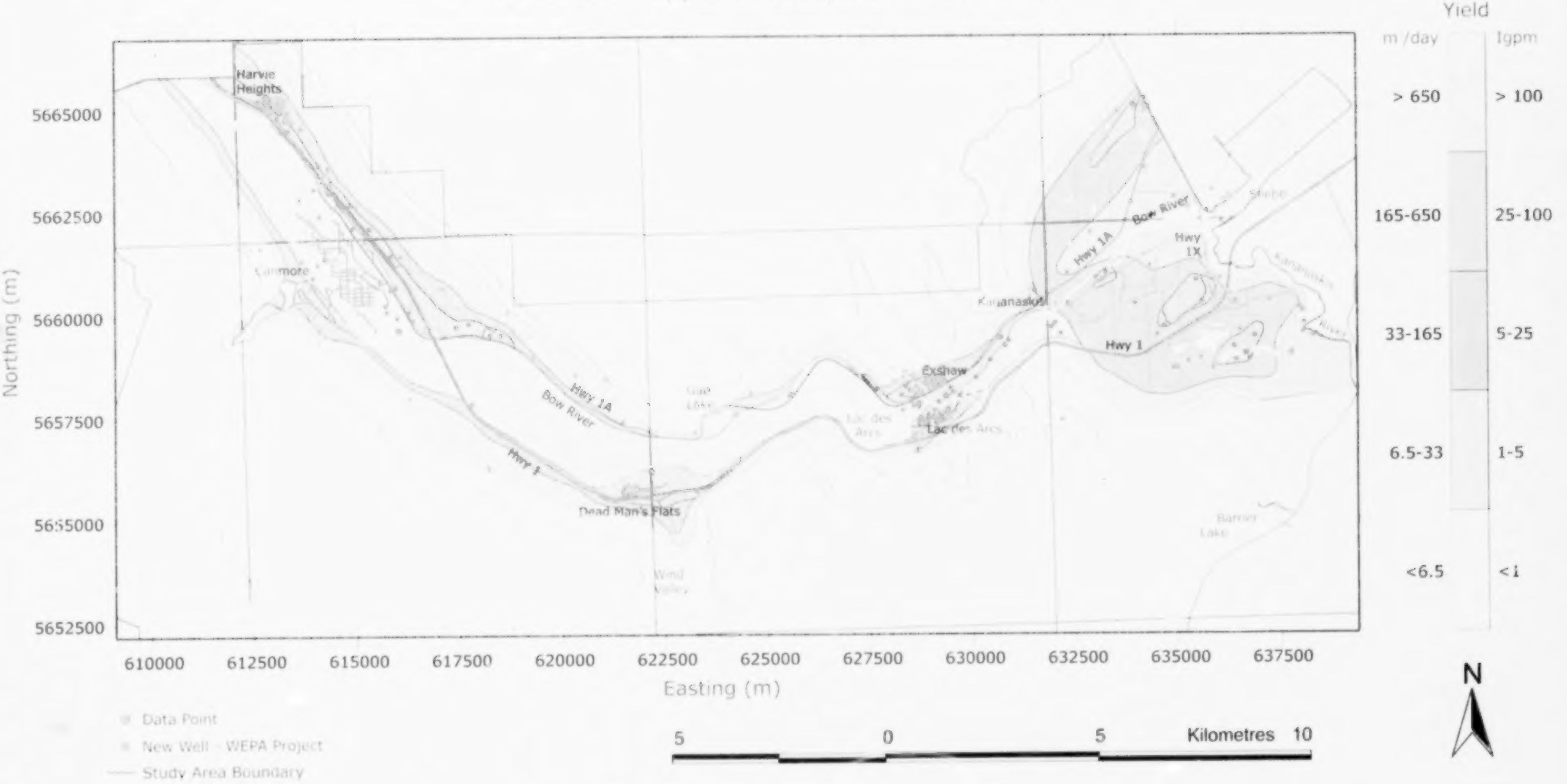
Yield Zones - Upper Drift Aquifer - Bow Valley


Yield
m³/day
Igpm
> 650
> 100
165-650
25-100
33-165
5-25
6.5-33
1-5
<6.5
<1
N
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Harvie Heights
Canmore
Hwy 1A
Bow River
Hwy 1
Gap Lake
Dead Man Flat
Wind Valley
Lac des Arcs
Lac des Arcs
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
Data Point
New Well - WEPA Project
Study Area Boundary
5
0
5
Kilometres 10

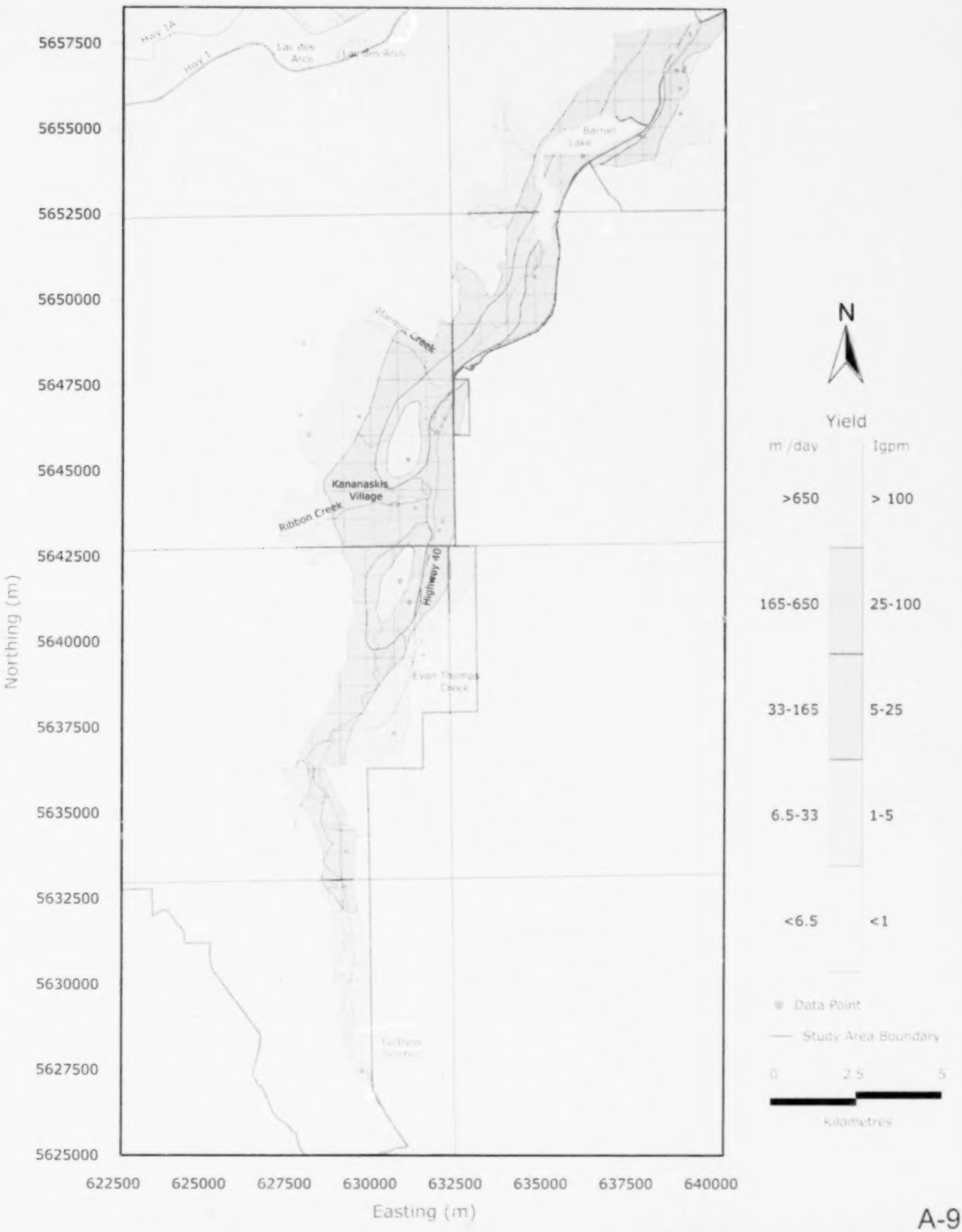
Yield Zones - Kananaskis Valley


Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot C
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
622500
625000
627500
630000
632500
635000
637500
640000
Easting (m)
N
Yield
m³/day
Igpm
>650
> 100
165-650
25-100
33-165
5-25
6.5-33
1-5
<6.5
<1
Data Point
Study Area Boundary
0
2.5
5
Kilometres

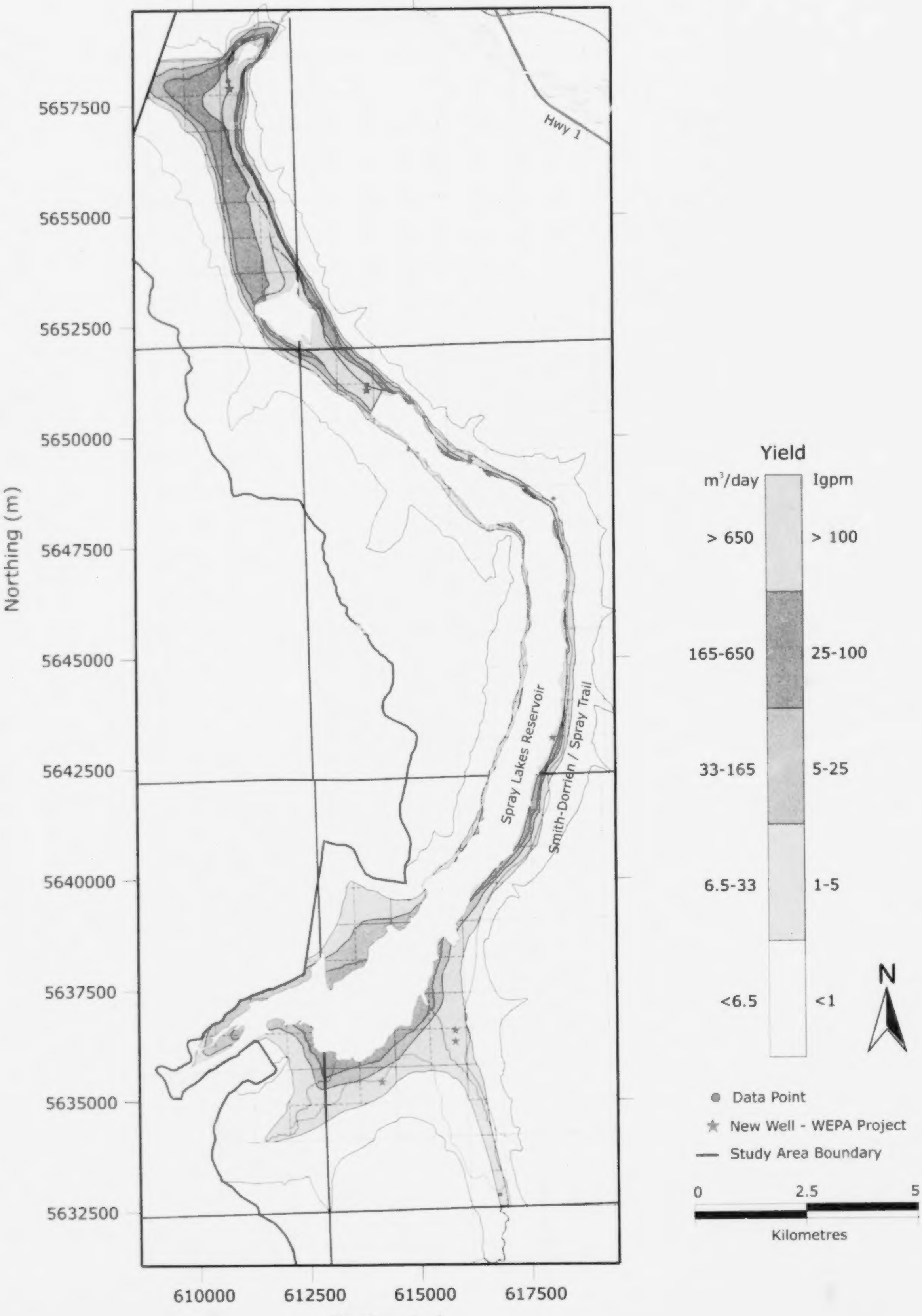
Yield Zones - Upper Drift Aquifer - Bow Valley


Harvie Heights
Canmore
Hwy 1A
Bow River
Hwy 1
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Exshaw
Lac des Arcs
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Data Point
New Well - WEPA Project
Study Area Boundary
5
0
5
Kilometres
10
N
Yield
m /day
Igpm
> 650
> 100
165-650
25-100
33-165
5-25
6.5-33
1-5
<6.5
<1

Yield Zones - Kananaskis Valley

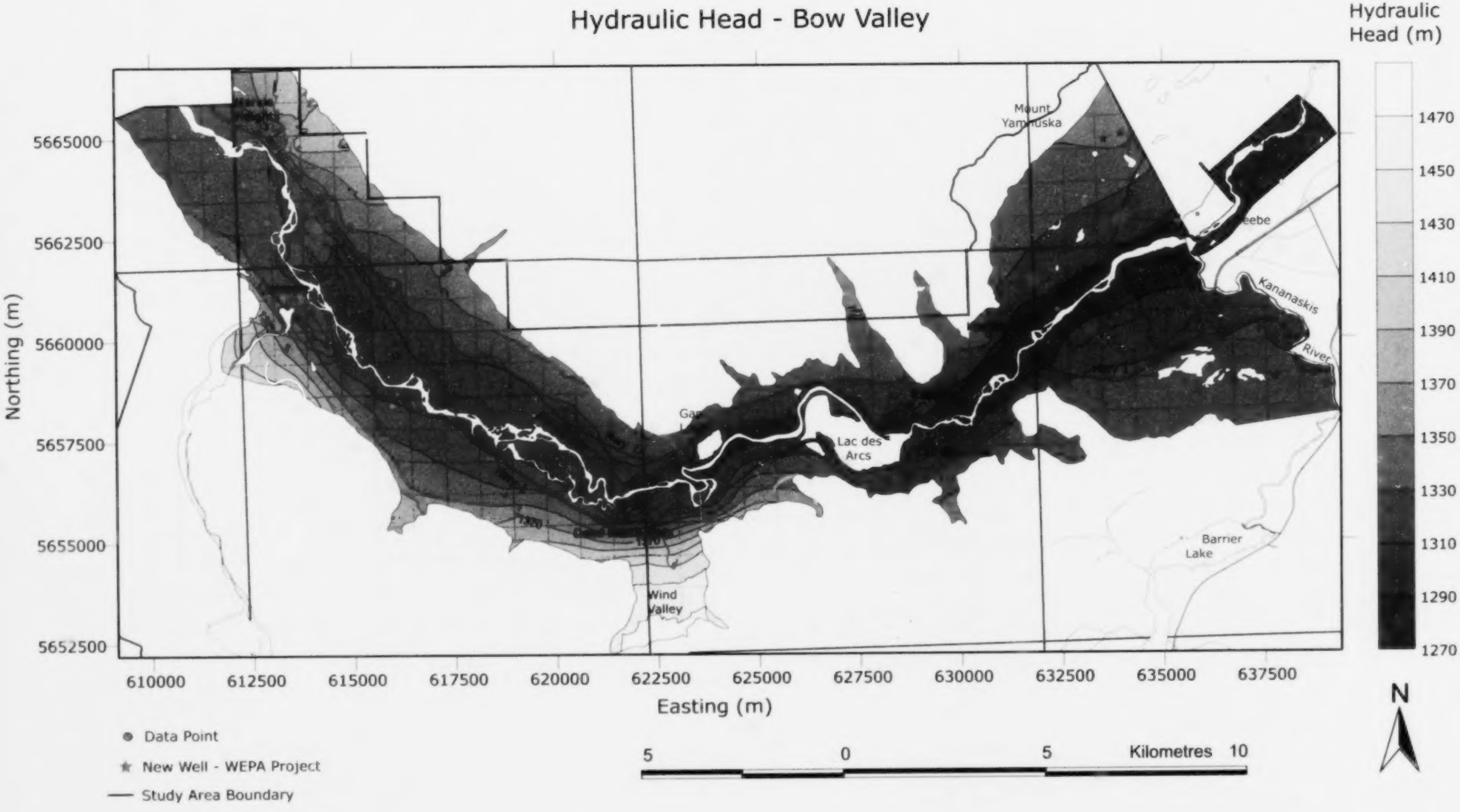

Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Northing (m)
622500
625000
627500
630000
632500
635000
637500
640000
Easting (m)
N
Yield
m /day
Igpm
>650
> 100
165-650
25-100
33-165
5-25
6.5-33
1-5
<6.5
<1
Data Point
Study Area Boundary
0
2.5
5
Kilometres

Yield Zones - Spray Lakes Valley

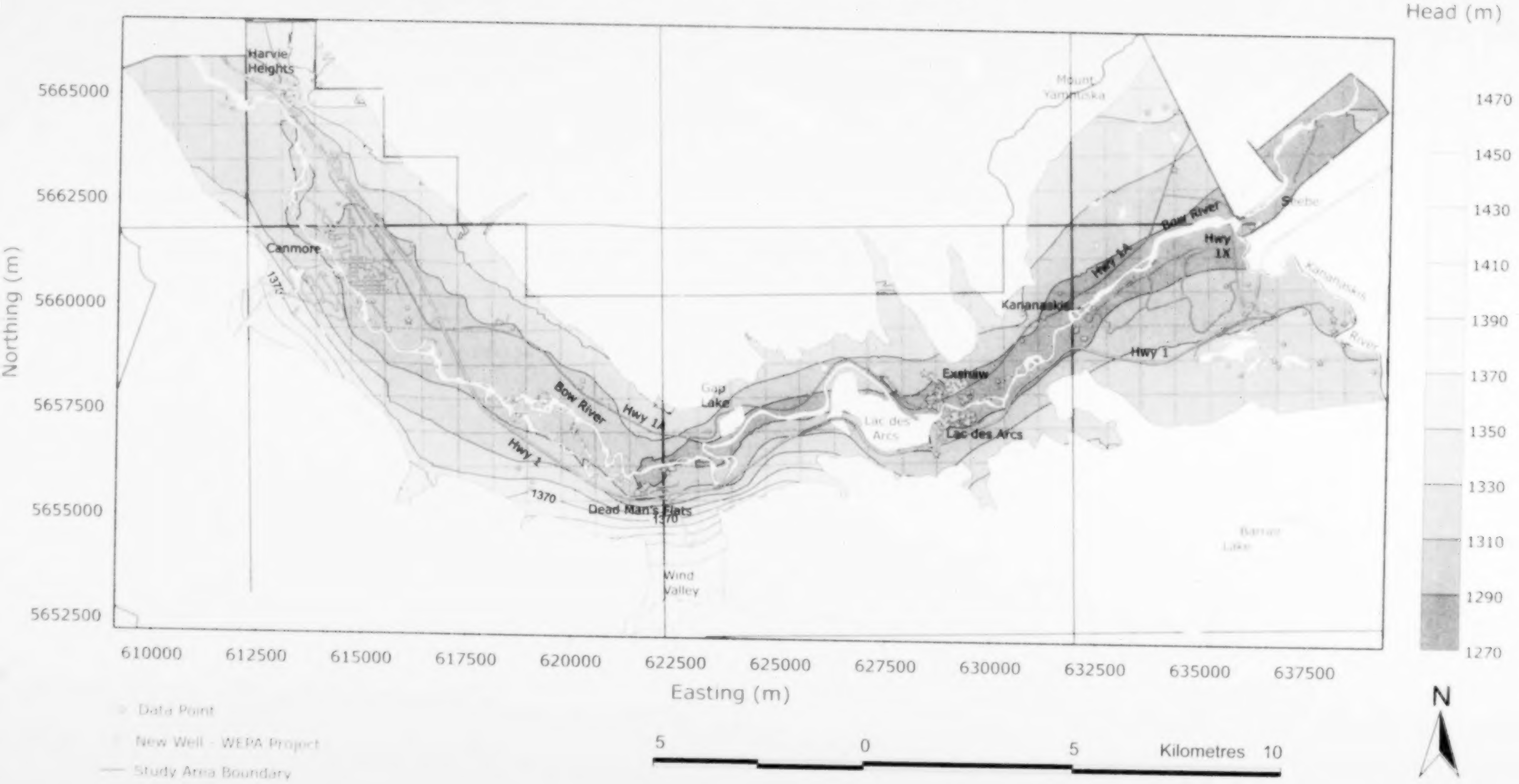


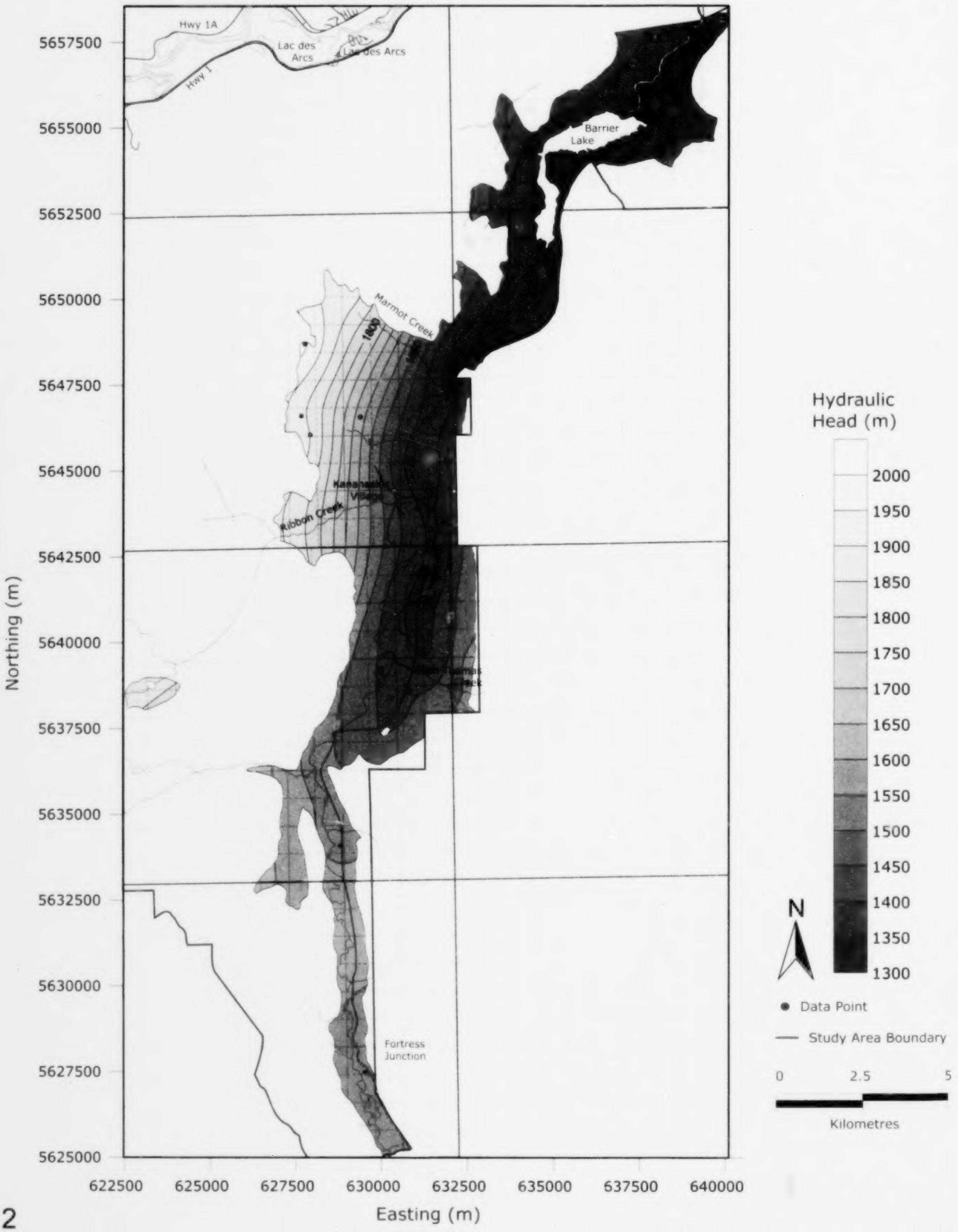
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Easting (m)
610000
612500
615000
617500
Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
Yield
m^3/day
Igpm
> 650
> 100
165-650
25-100
33-165
5-25
6.5-33
1-5
<6.5
<1
N
● Data Point
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

Hydraulic Head - Bow Valley


Hydraulic Head (m)
1470
1450
1430
1410
1390
1370
1350
1330
1310
1290
1270
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Mount Yamnuska
eebe
Kananaskis River
Lac des Arcs
Ga
Wind Valley
Barrier Lake
1300
1320
N
5
0
5
Kilometres 10
● Data Point
★ New Well - WEPA Project
— Study Area Boundary

Hydraulic Head - Bow Valley

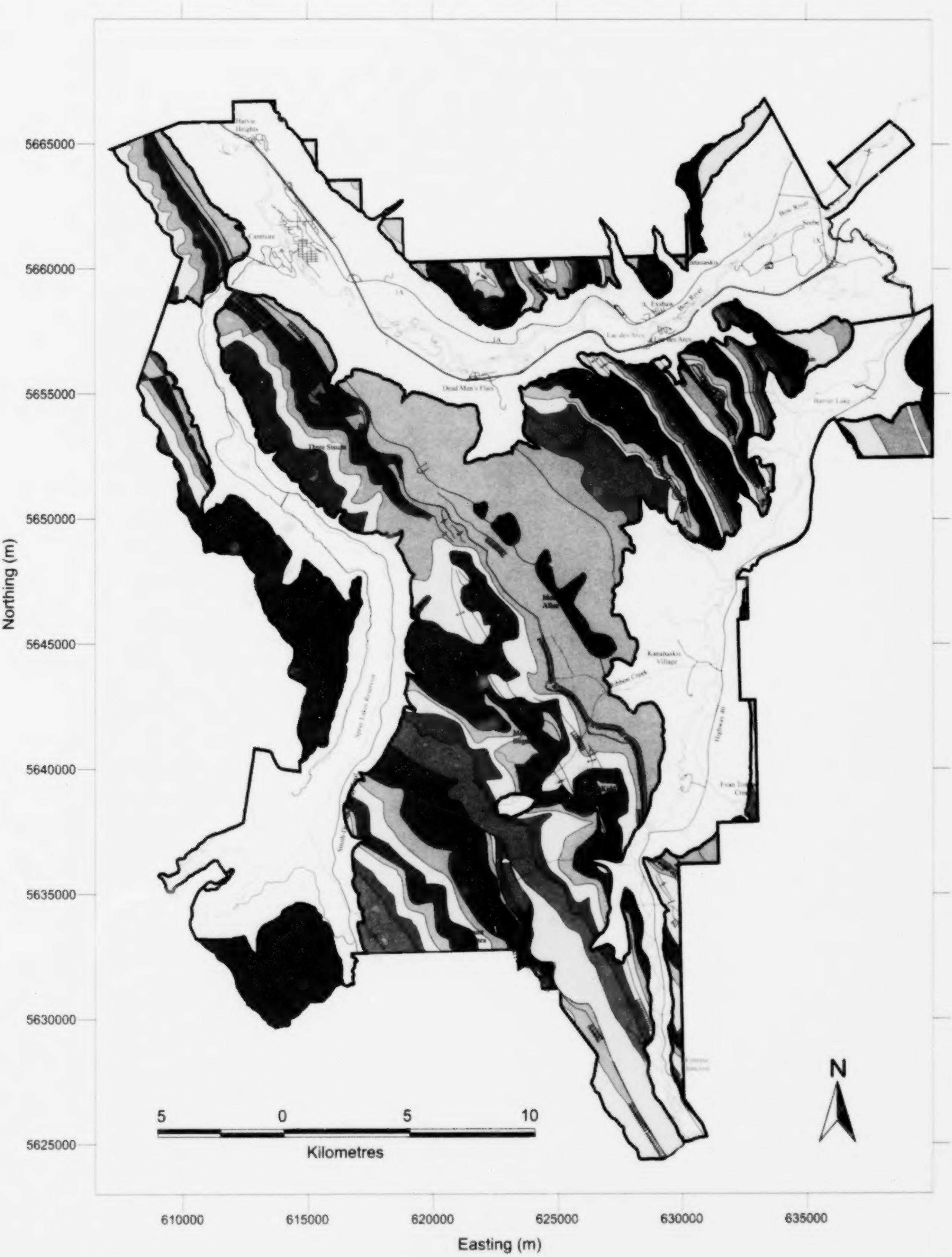

Hydraulic Head (m)
1470
1450
1430
1410
1390
1370
1350
1330
1310
1290
1270
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Harvie Heights
Canmore
1370
Bow River
Hwy 1A
Hwy 1
1370
Dead Man's Flats
1370
Wind Valley
Gap Lake
Lac des Arcs
Lac des Arcs
Exshaw
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Mount Yamnuska
Barrier Lake
Data Point
New Well - WEPA Project
Study Area Boundary
5
0
5
Kilometres 10
N



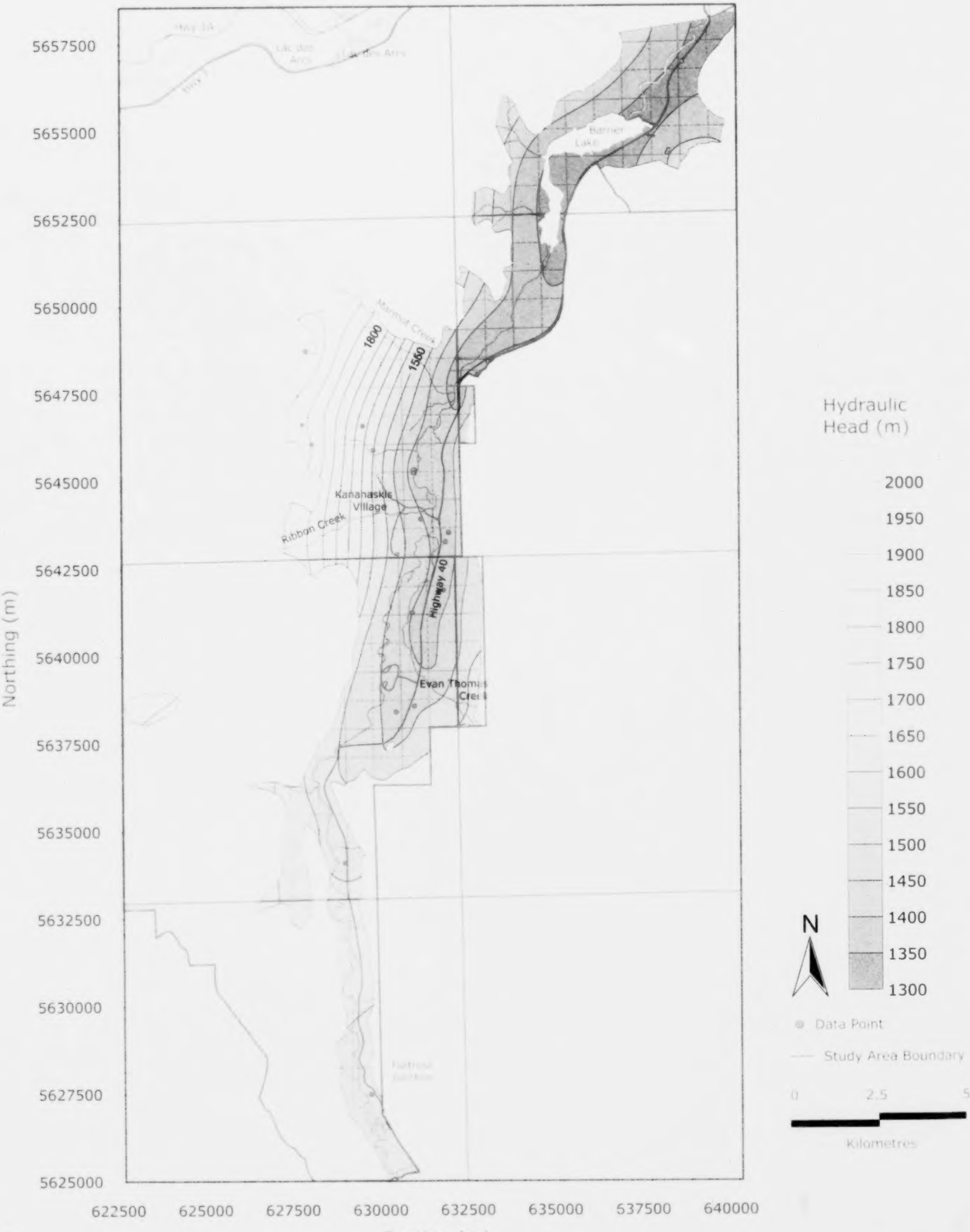
Hydraulic Head - Kananaskis Valley

Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
1800
Kananaskis Village
Ribbon Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
Hydraulic Head (m)
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
N
Data Point
Study Area Boundary
0
2.5
5
Kilometres

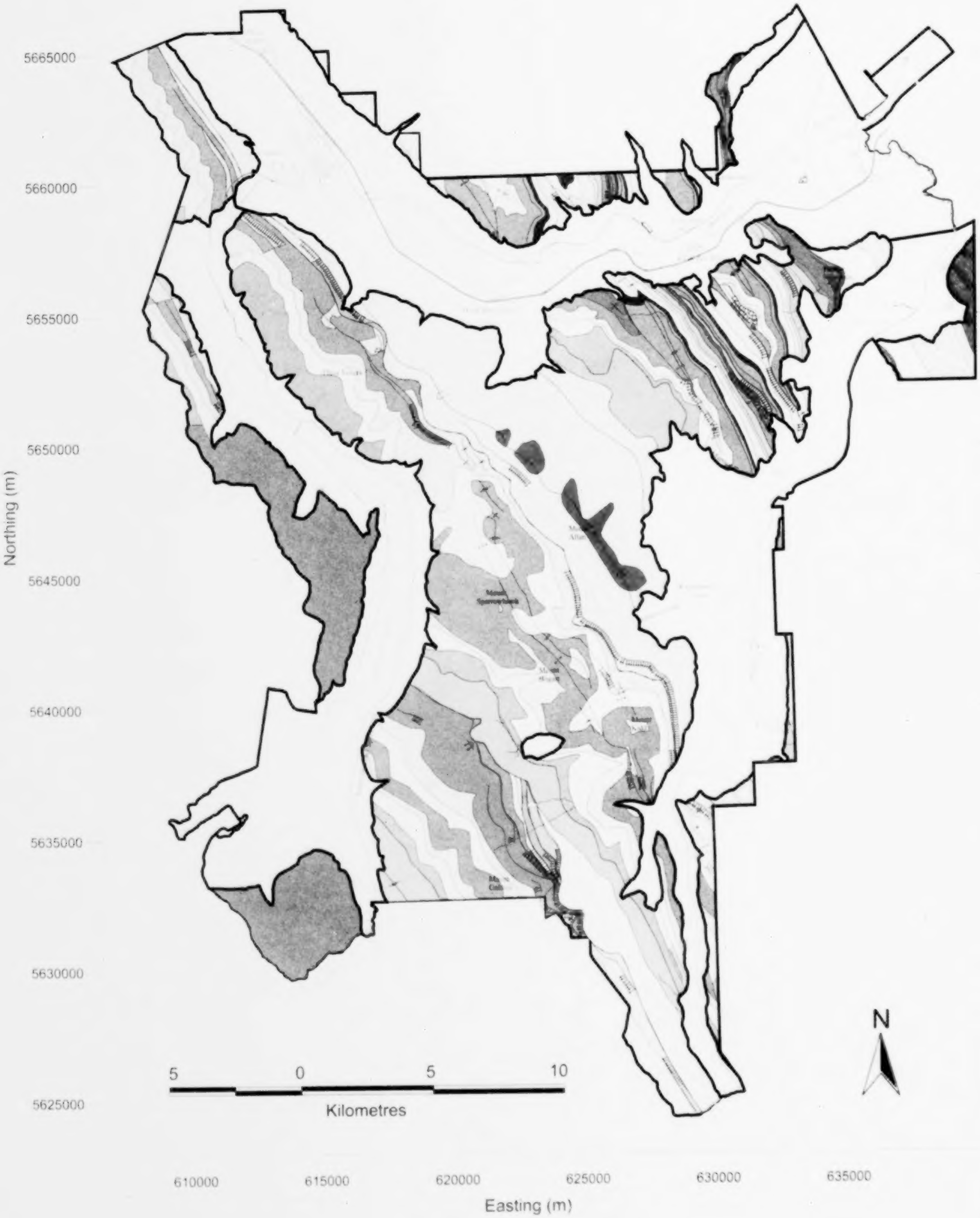
Bedrock Geology - Canmore Corridor and Northwestern Kananaskis Country


Northing (m)
5665000
5660000
5655000
5650000
5645000
5640000
5635000
5630000
5625000
Easting (m)
610000
615000
620000
625000
630000
635000
5
0
5
10
Kilometres
N
Harvie Heights
Canmore
Dead Man's Flats
Three Sisters
Lac des Arcs
Exshaw
Bow River
Kananaskis
Barrier Lake
Kananaskis Village
Ribbon Creek
Highway 40
Spray Lakes Reservoir
Evan Thomas Creek
1A

Hydraulic Head - Kananaskis Valley


Hwy 1A
Lac des Arcs
Lac des Arcs
Hwy 1
Barrier Lake
Marmot Creek
1800
1550
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
Hydraulic Head (m)
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
N
Data Point
Study Area Boundary
0
2.5
5
Kilometres

Bedrock Geology - Canmore Corridor and Northwestern Kananaskis Country


5665000
5660000
5655000
5650000
5645000
5640000
5635000
5630000
5625000
Northing (m)
5
0
5
10
Kilometres
N
610000
615000
620000
625000
630000
635000
Easting (m)

Legend

Era	Period	Group		Unit
Cenozoic	Quaternary and Recent		□	Drift
Mesozoic	Upper Cretaceous		□	KBZ-l Brazeau - Lower Part
		Alberta Group	▨	KWp Wapiabi
			□	KCa Cardium Formation
			▨	KBk Blackstone
	Lower Cretaceous / Jurassic	Blairmore Group	■	KBL Beaver Mines, Mill Creek, Cadomin and Gladstone
		Kootenay Group	▨	JKK
	Jurassic		□	JF Fernie
	Triassic	Spray River Group	▨	SR Whitehorse and Sulphur Mountain
Paleozoic	Upper Carboniferous and Permian	Rocky Mountain Group	■	CPRM Rocky Mountain Group
	Lower Carboniferous	Rundle Group	□	CEt Etherington
			▨	MPPu Mount Head and Etherington
			▨	CMH Mount Head
			■	CLv Livingstone
			■	CSh Shunda
			■	CPk Pekisko
	Lower Carboniferous and Upper Devonian		□	DCEB Exshaw and Banff
	Upper Devonian		▨	DPa Palliser
			▨	DAx Alexo
		Fairholme Group	▨	DSx Southesk
			■	DCn Cairn
			■	Fairholme Group (not differentiated)
	Upper and Middle Cambrian		▨	Celx Waterfowl, Sullivan, Lyell, Bison Creek, Mistaya and Eldon
			■	CPE Pika and Eldon
			■	CCS Cathedral and Stephen
			■	Not Mapped

Geology compiled by Kevin Nipp
Sources of Geological Information:
Hamilton, W.N., M.C. Price and D.K Chao, 1997. *Geology of the Bow Corridor.*
Scale, Alberta Geological Survey Map 232A, Scale 1:50,000
McMechan, M.E. 1995. *Geology, Rocky Mountain Foothills and Front Ranges in Kananaskis Country, Alberta*: Geological Suvey of Canada, Map 1865A, Scale 1:100,000
Walter, D.J. 1978. *Geology: Calgary, Alberta-British Columbia, NTS 82-O*,
Geological Survey of Canada Map 1457A, Scale 1:250,000

Appendix B

Water Chemistry

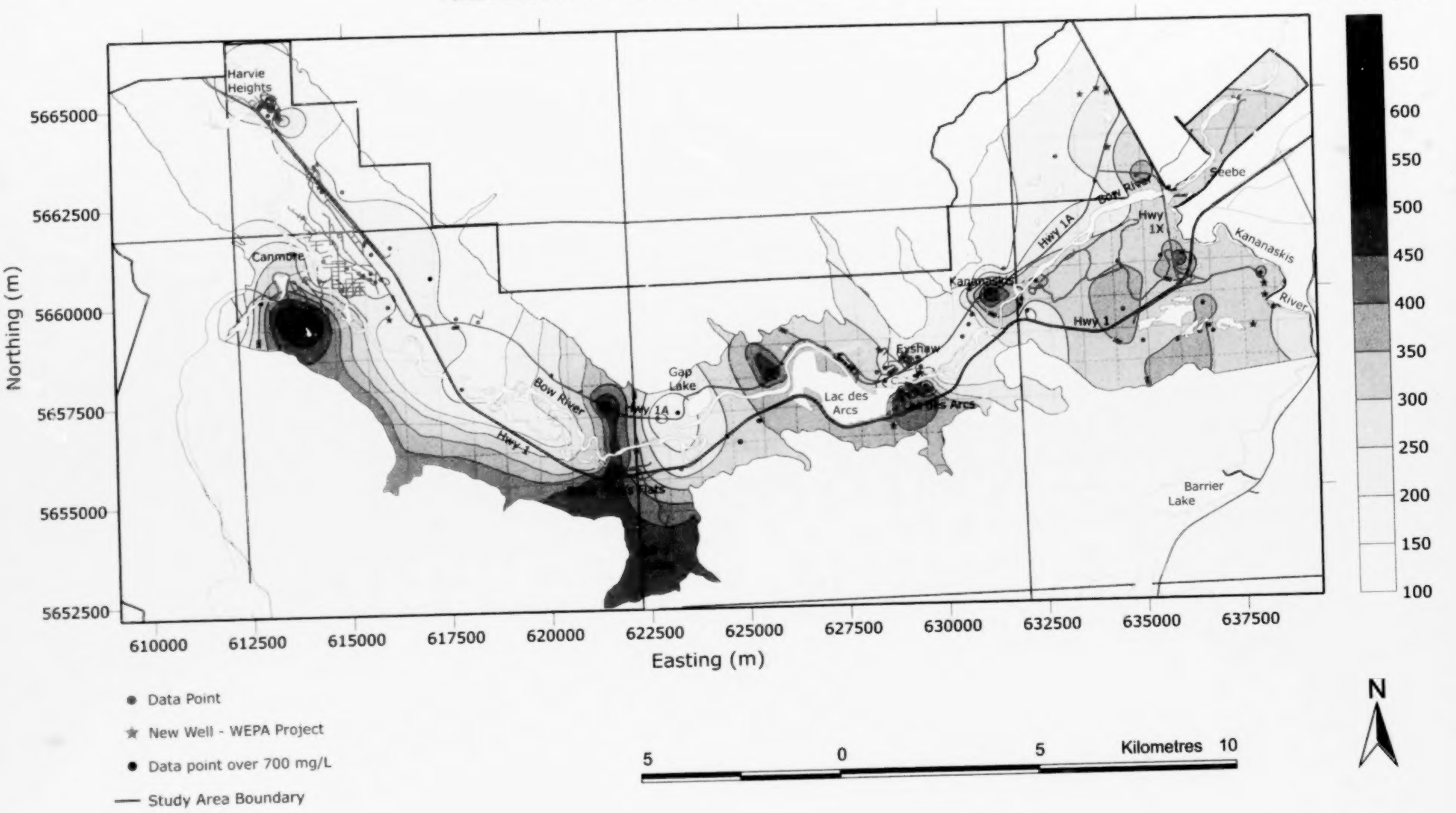
Total Dissolved Solids – Upper Drift Aquifer – Bow Valley
Total Dissolved Solids – Drift Aquifer - Kananaskis Valley
Total Dissolved Solids – Drift Aquifer – Spray Lakes Valley
Water Chemistries by Type – Bow Valley
Water Chemistries by Type – Kananaskis Valley
Water Chemistries by Type – Spray Lakes Valley
Nitrates – Bow Valley
Nitrates – Kananaskis Valley
Nitrates – Spray Lakes Valley
Iron – Bow Valley
Iron – Kananaskis Valley
Iron – Spray Lakes Valley

Comparison of Groundwater Chemistry by Region:

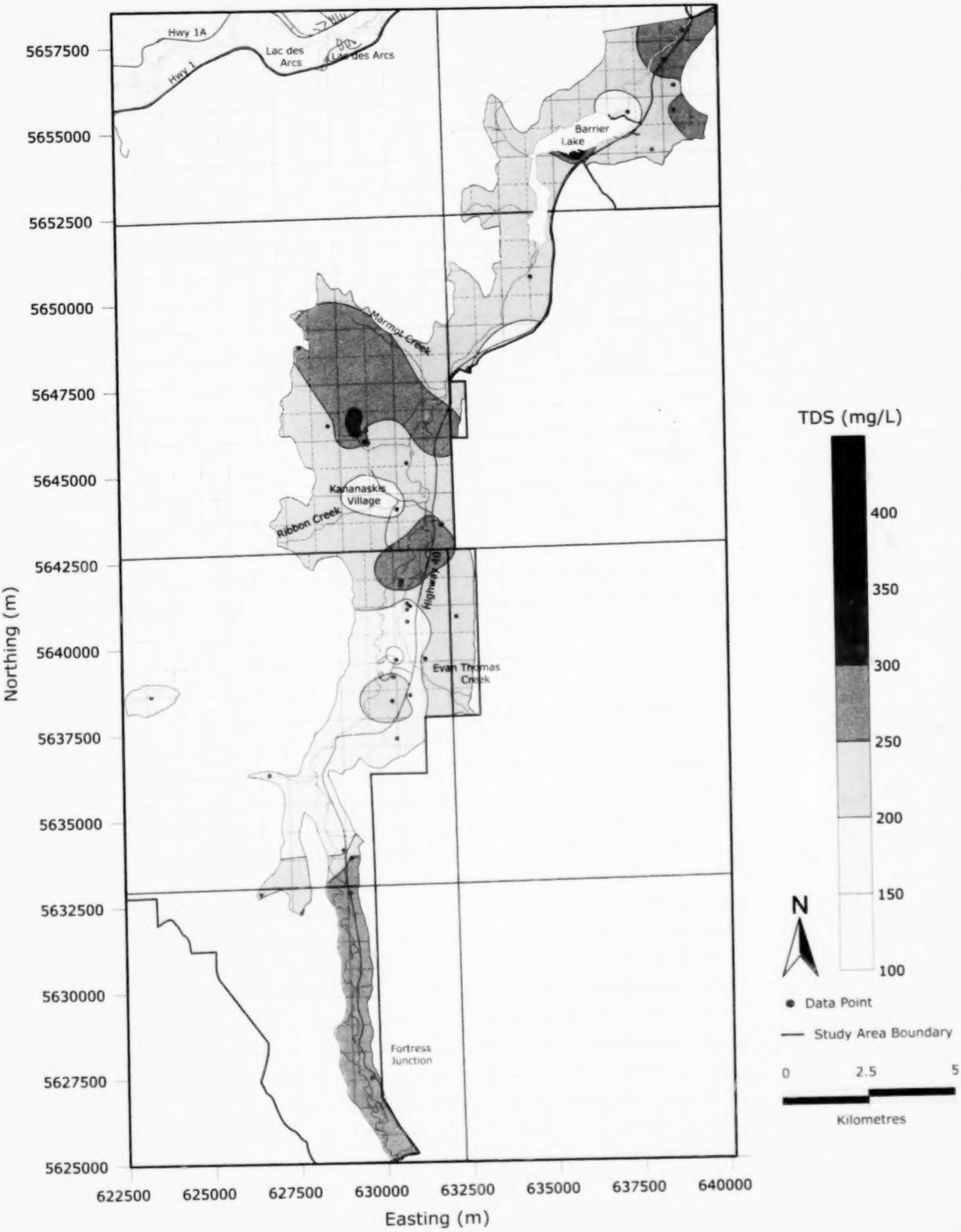
Harvie Heights
Canmore
Dead Man's Flats / Gap
Exshaw
Lac des Arcs
Many Springs / Deep Aquifer / Kananaskis Siding
Bow Valley Provincial Park / Yamnuska – Seebe
Barrier / Tim Horton Ranch
Marmot Creek Basin
Kananaskis Valley
Spray Valley

Water Analysis Guide

Total Dissolved Solids - Drift Aquifer - Bow Valley



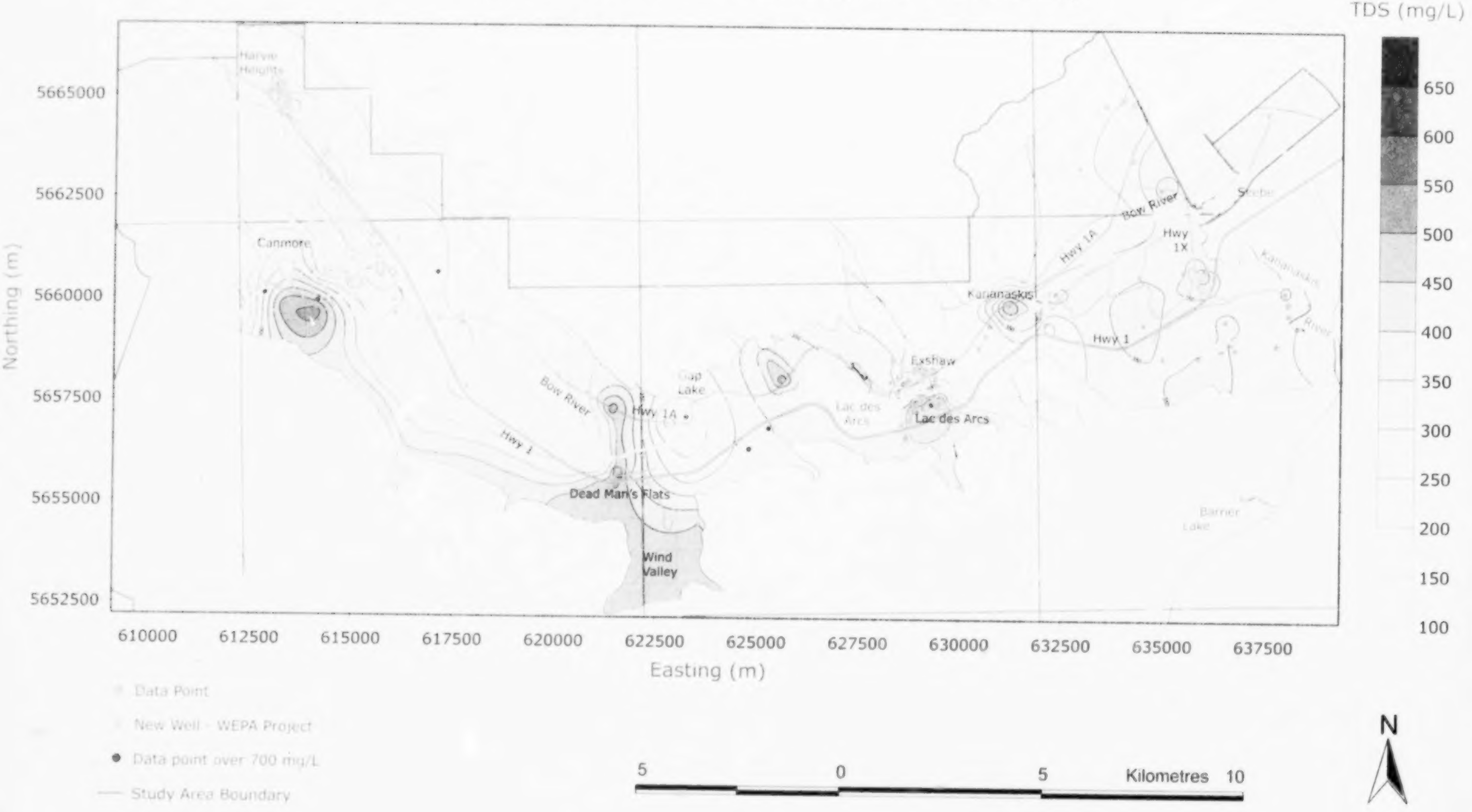
TDS (mg/L)
650
600
550
500
450
400
350
300
250
200
150
100
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Harvie Heights
Canmore
Bow River
Hwy 1
Hwy 1A
Gap Lake
Lac des Arcs
Exshaw
Lac des Arcs
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
● Data Point
★ New Well - WEPA Project
● Data point over 700 mg/L
— Study Area Boundary
5
0
5
Kilometres 10
N



Total Dissolved Solids - Kananaskis Valley

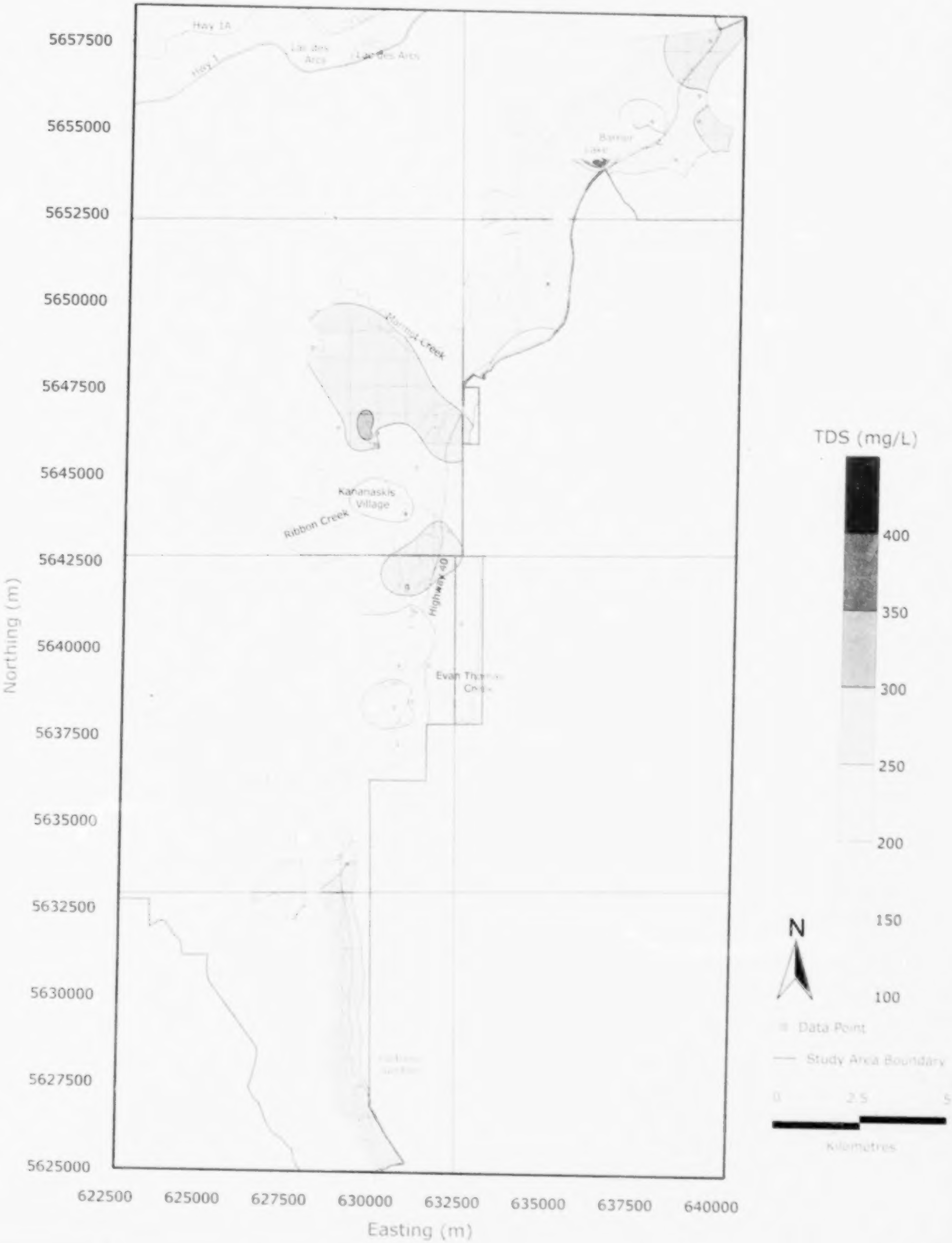
Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
TDS (mg/L)
400
350
300
250
200
150
100
N
Data Point
Study Area Boundary
0
2.5
5
Kilometres

Total Dissolved Solids - Drift Aquifer - Bow Valley

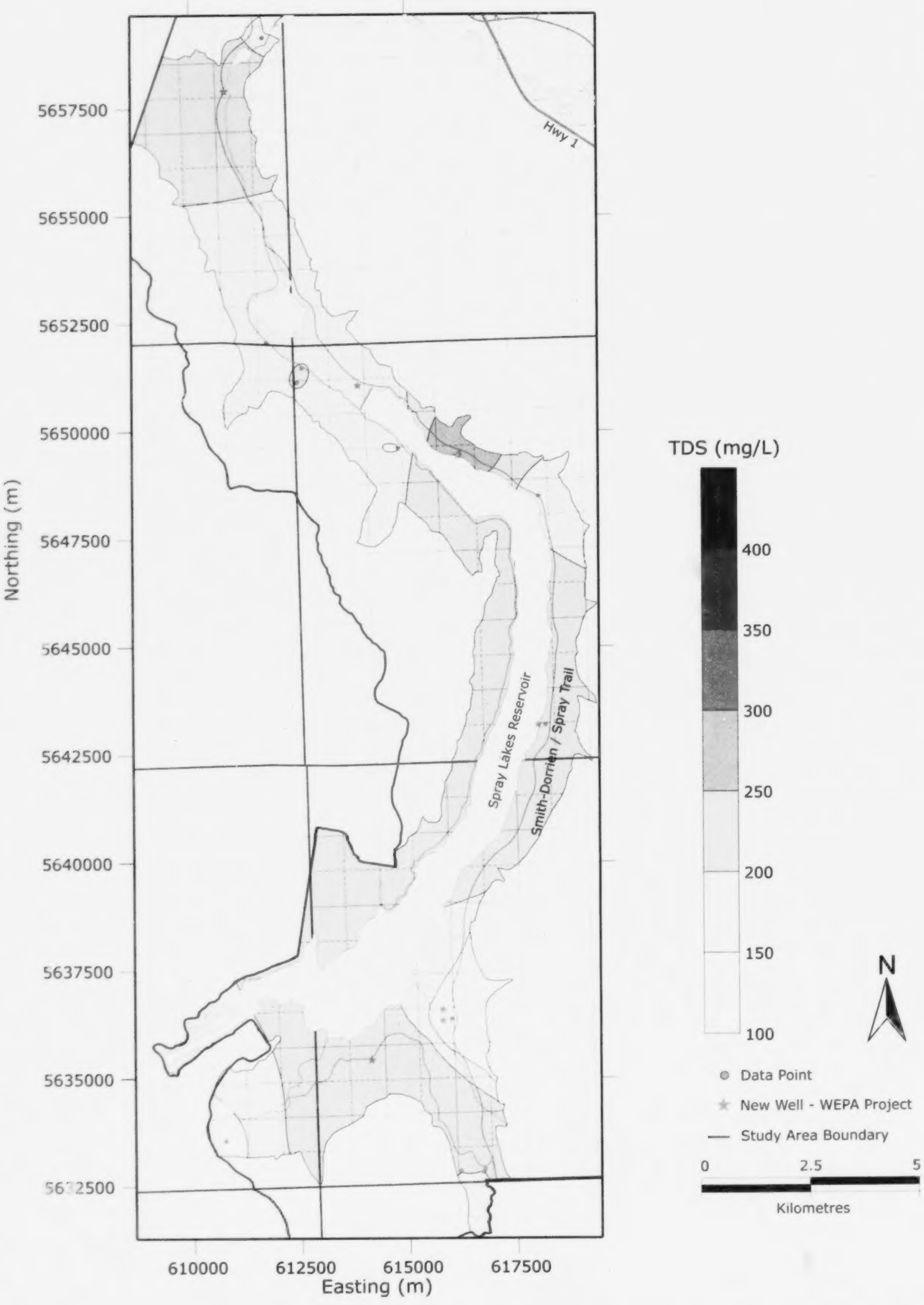


TDS (mg/L)
650
600
550
500
450
400
350
300
250
200
150
100
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Harvie Heights
Canmore
Bow River
Hwy 1
Hwy 1A
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Exshaw
Lac des Arcs
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Hwy 1
Kananaskis River
Barrier Lake
Data Point
New Well - WEPA Project
Data point over 700 mg/L
Study Area Boundary
5
0
5
Kilometres
10
N

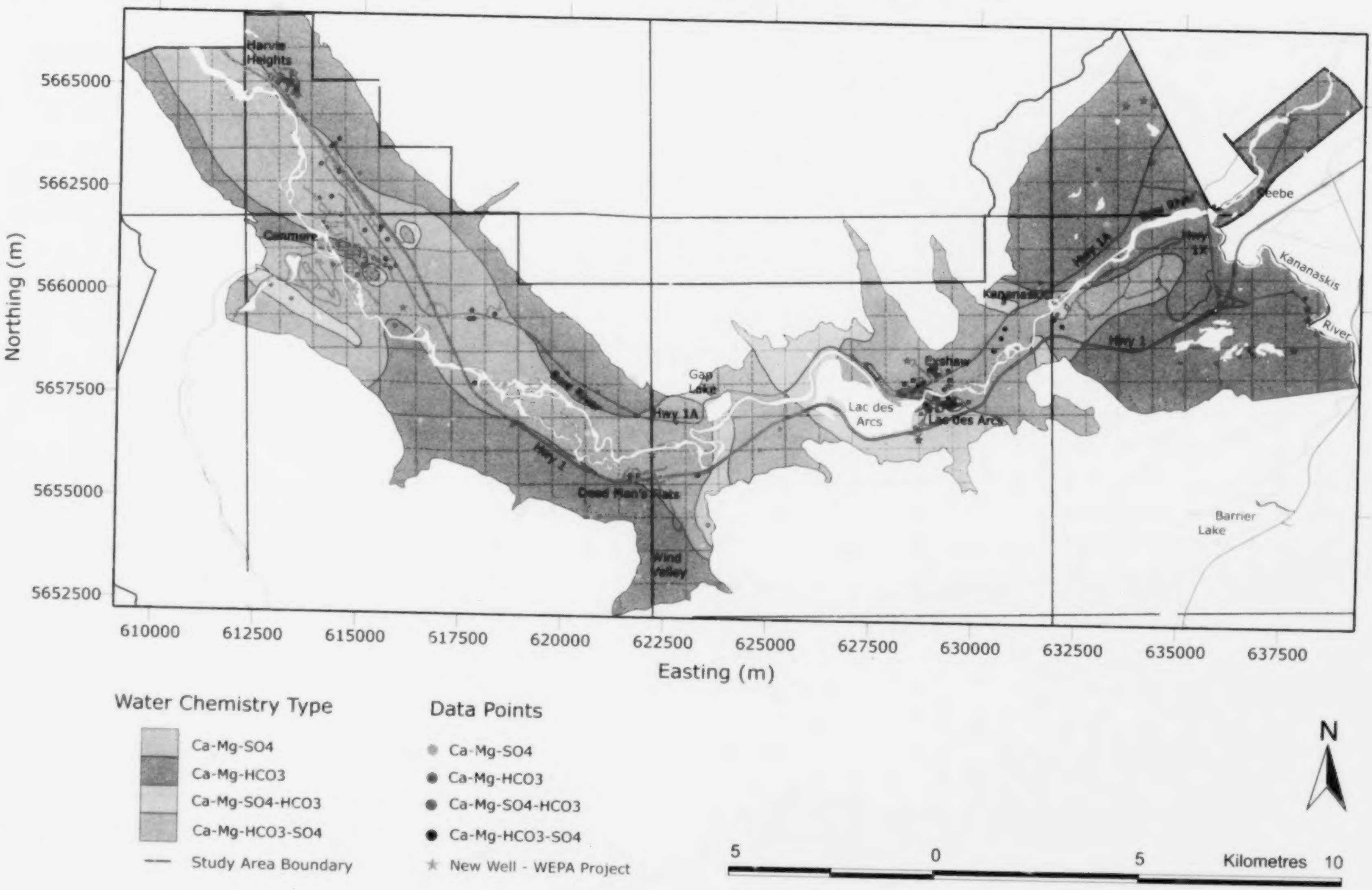
Total Dissolved Solids - Kananaskis Valley


Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
TDS (mg/L)
400
350
300
250
200
150
100
N
Data Point
Study Area Boundary
0
2.5
5
Kilometres

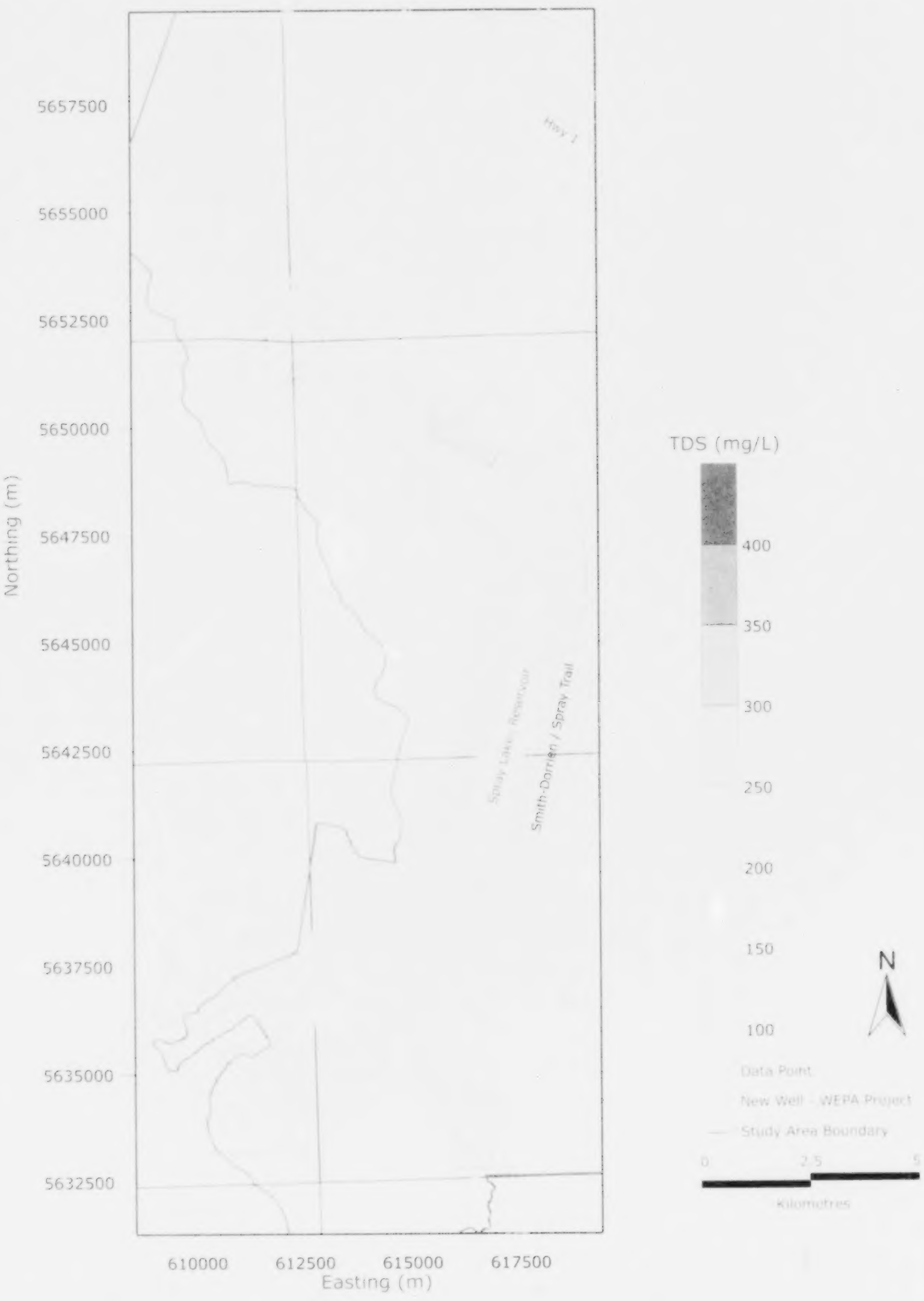
Total Dissolved Solids - Drift Aquifer - Spray Lakes Valley


Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Easting (m)
610000
612500
615000
617500
TDS (mg/L)
400
350
300
250
200
150
100
N
Data Point
New Well - WEPA Project
Study Area Boundary
0
2.5
5
Kilometres

Water Chemistries by Type - Bow Valley

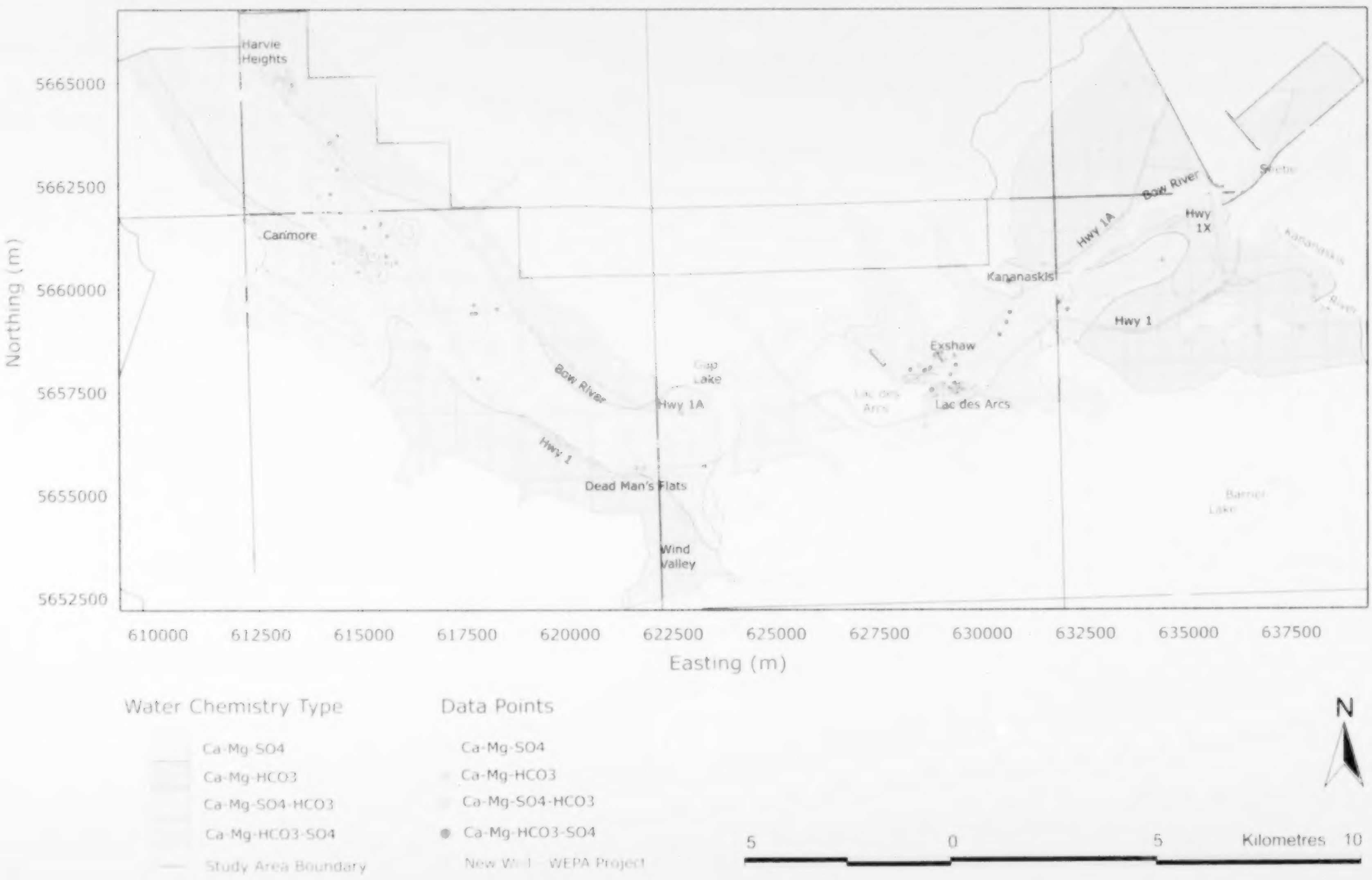

Harvie Heights
Canmore
Gap Lake
Hwy 1A
Hwy 1
Dead Man's Flats
Wind Valley
Lac des Arcs
Lac des Arcs
Exshaw
Kananaskis
Hwy 1A
Hwy 1X
Seebe
Kananaskis River
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Easting (m)
Water Chemistry Type
Ca-Mg-SO4
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
Study Area Boundary
Data Points
Ca-Mg-SO4
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
New Well - WEPA Project
N
5
0
5
Kilometres 10

Total Dissolved Solids - Drift Aquifer - Spray Lakes Valley

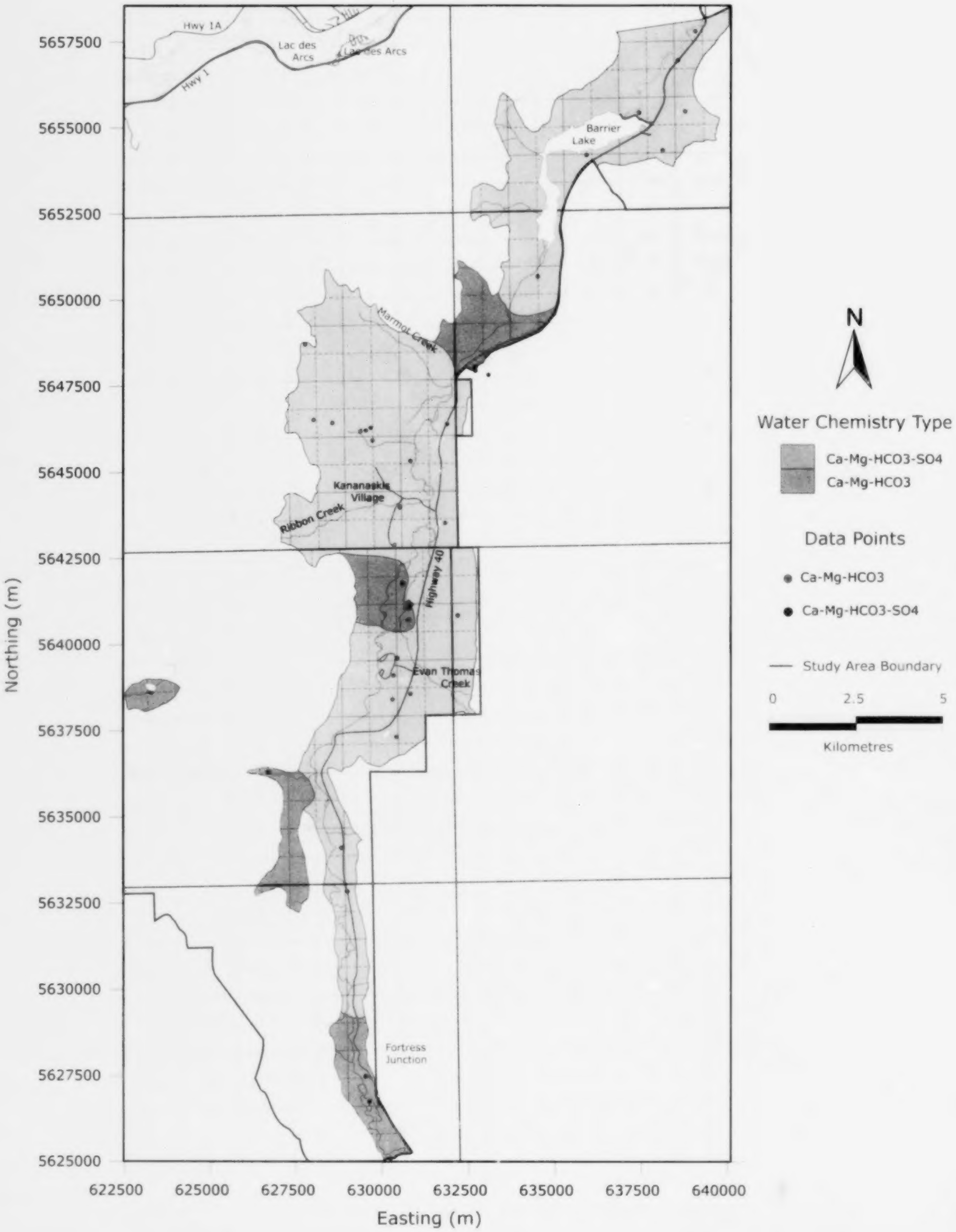


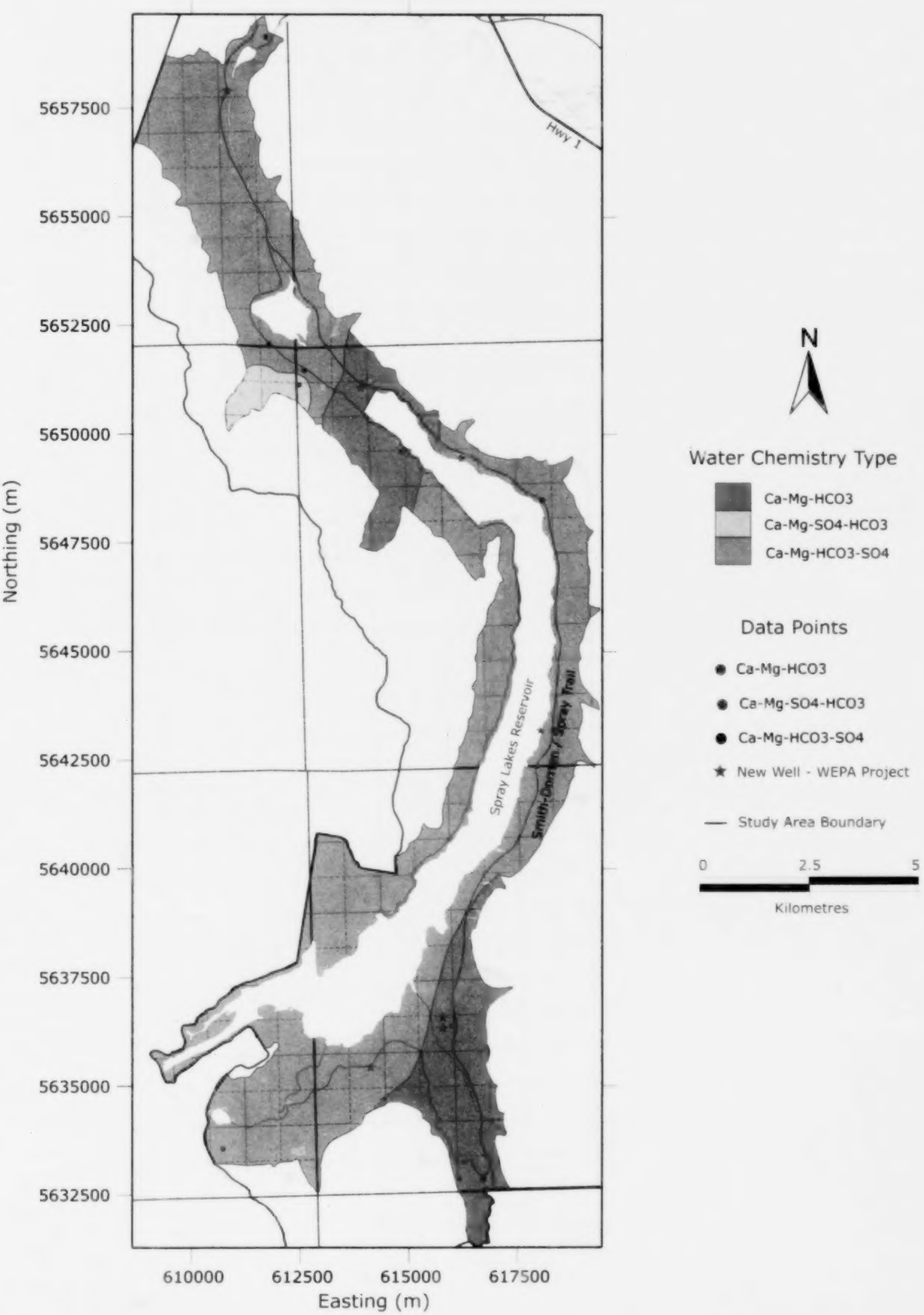
Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Easting (m)
610000
612500
615000
617500
TDS (mg/L)
400
350
300
250
200
150
100
N
Data Point
New Well - WEPA Project
Study Area Boundary
0
2.5
5
Kilometres

Water Chemistries by Type - Bow Valley


Harvie Heights
Canmore
Bow River
Hwy 1
Dead Man's Flats
Wind Valley
Gap Lake
Hwy 1A
Lac des Arcs
Lac des Arcs
Exshaw
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Easting (m)
Water Chemistry Type
Ca-Mg-SO4
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
Study Area Boundary
Data Points
Ca-Mg-SO4
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
New Well - WEPA Project
N
5
0
5
Kilometres
10

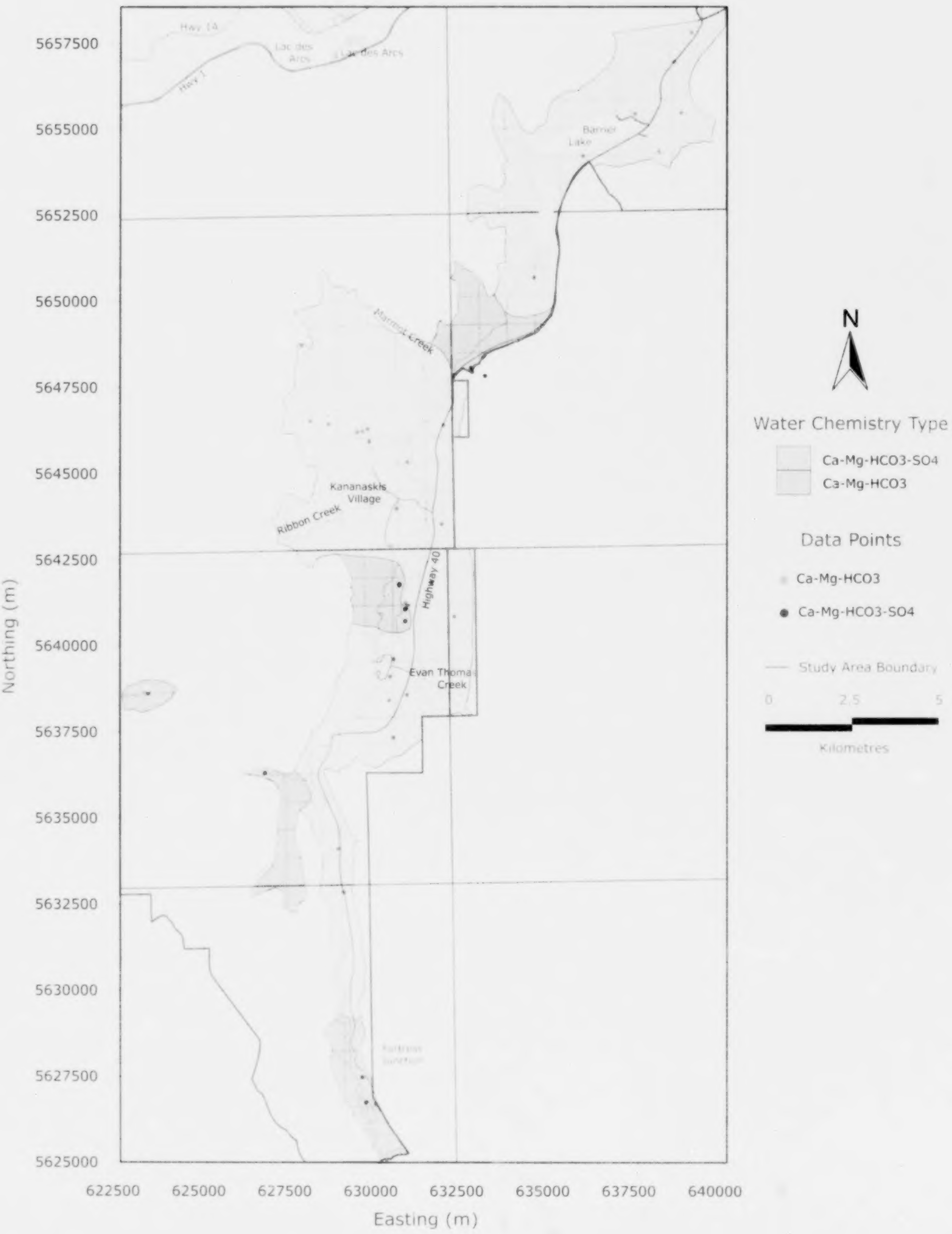
Water Chemistries by Type - Kananaskis Valley


Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
N
Water Chemistry Type
Ca-Mg-HCO3-SO4
Ca-Mg-HCO3
Data Points
Ca-Mg-HCO3
Ca-Mg-HCO3-SO4
Study Area Boundary
0
2.5
5
Kilometres

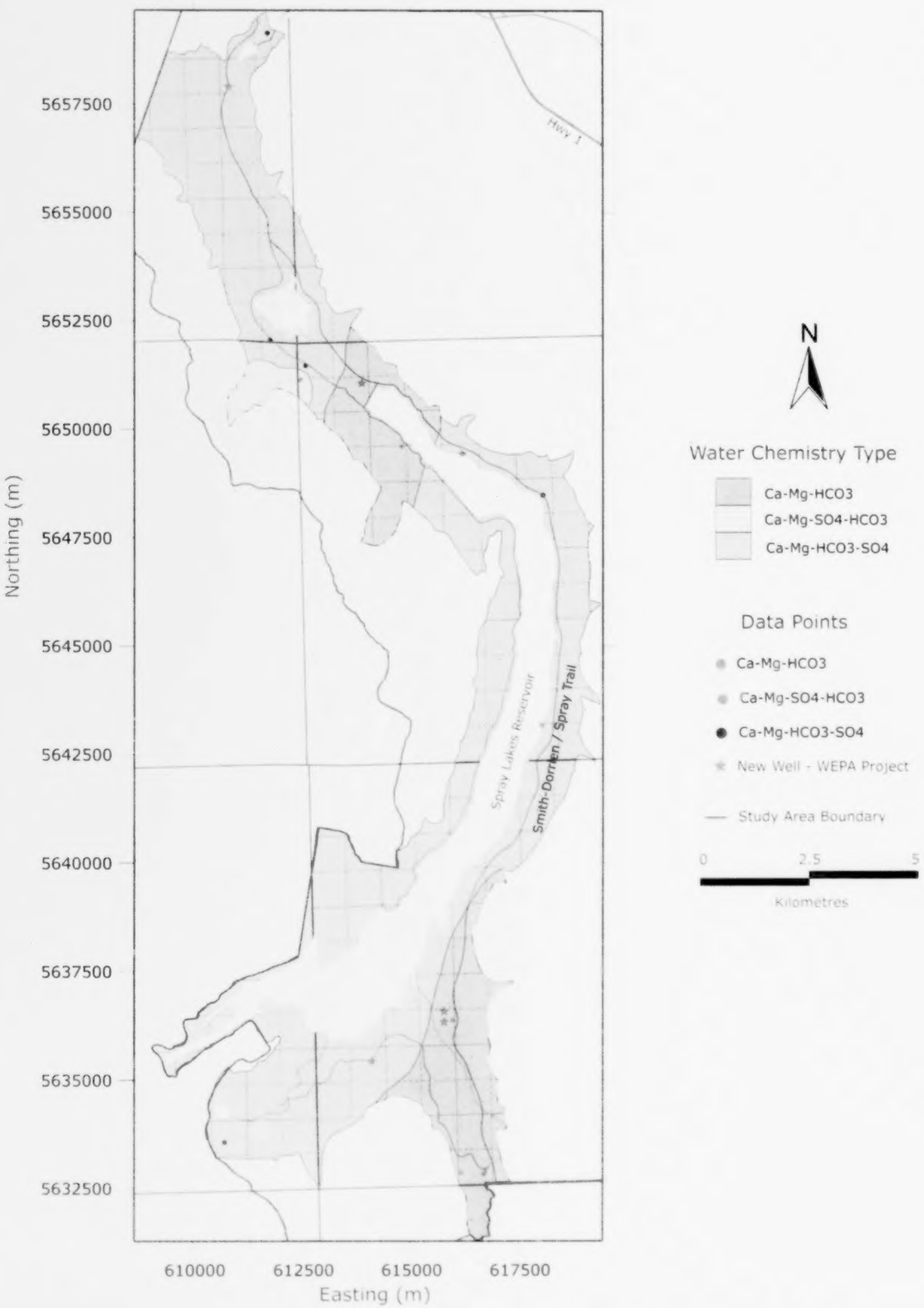

Water Chemistries by Type - Spray Lakes Valley

Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
610000
612500
615000
617500
Easting (m)
Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
N
Water Chemistry Type
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
Data Points
● Ca-Mg-HCO3
● Ca-Mg-SO4-HCO3
● Ca-Mg-HCO3-SO4
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

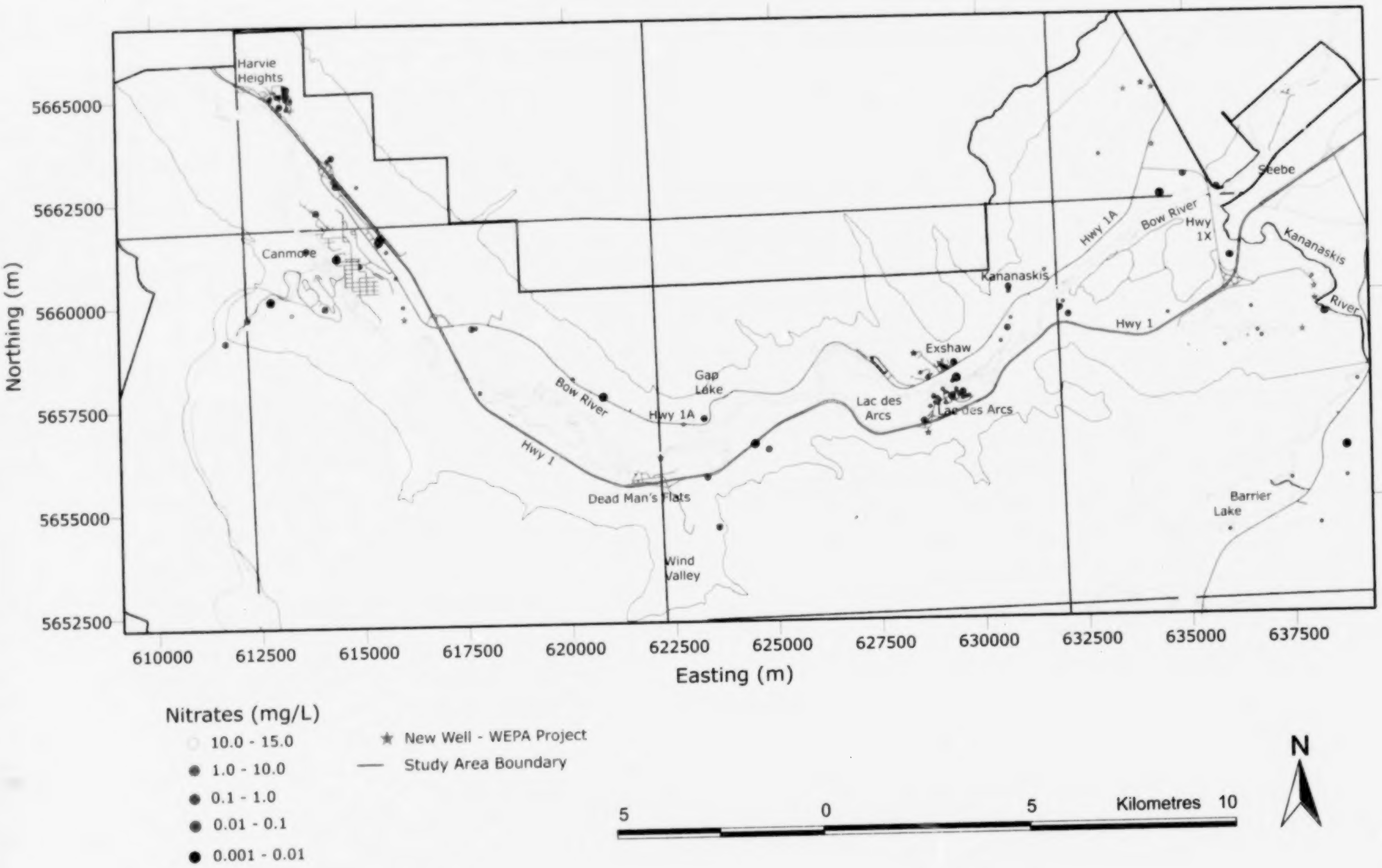
Water Chemistries by Type - Kananaskis Valley


Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000
N
Water Chemistry Type
Ca-Mg-HCO3-SO4
Ca-Mg-HCO3
Data Points
Ca-Mg-HCO3
Ca-Mg-HCO3-SO4
Study Area Boundary
0
2.5
5
Kilometres

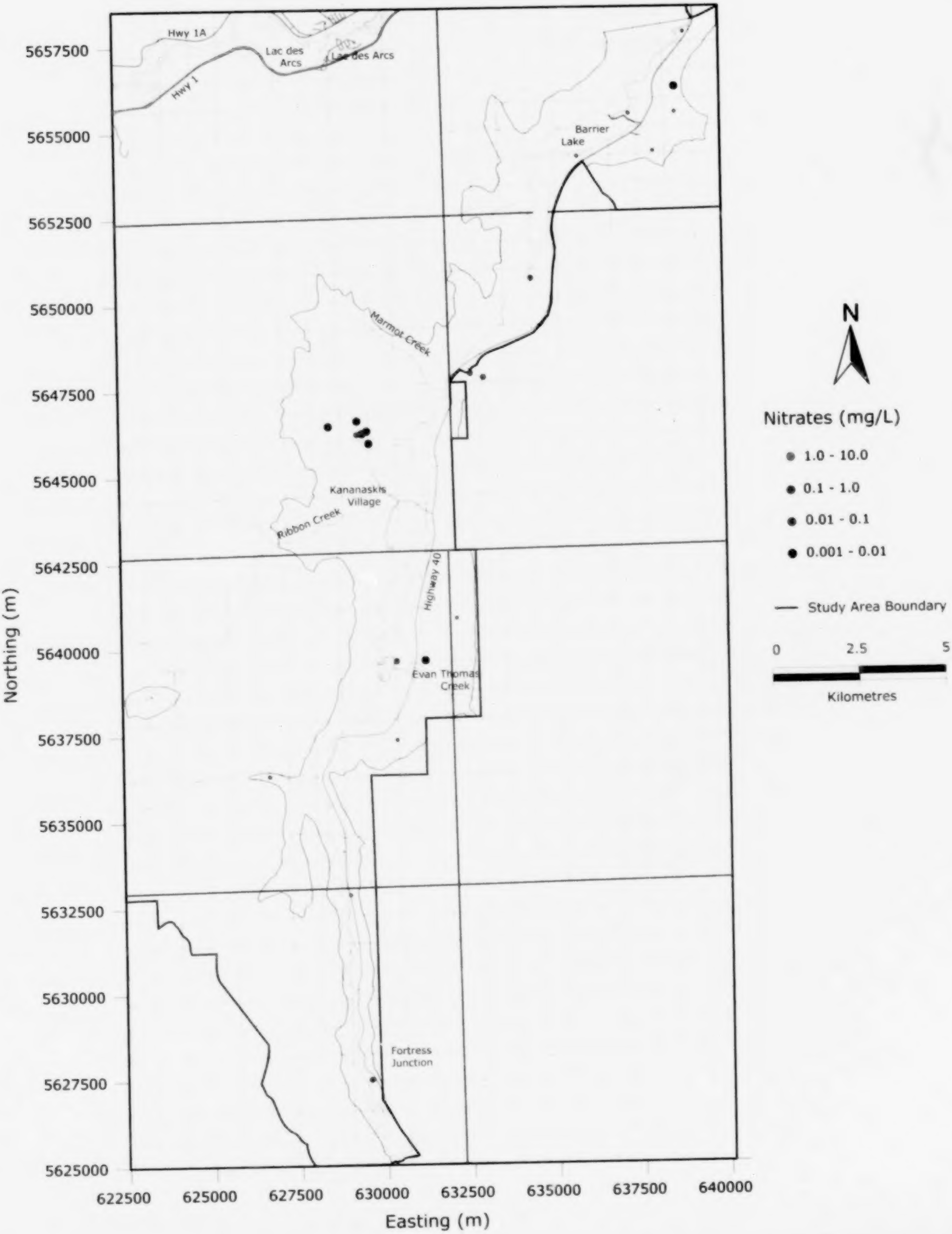
Water Chemistries by Type - Spray Lakes Valley


Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Northing (m)
610000
612500
615000
617500
Easting (m)
N
Water Chemistry Type
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
Data Points
Ca-Mg-HCO3
Ca-Mg-SO4-HCO3
Ca-Mg-HCO3-SO4
New Well - WEPA Project
Study Area Boundary
0
2.5
5
Kilometres

Nitrates - Bow Valley

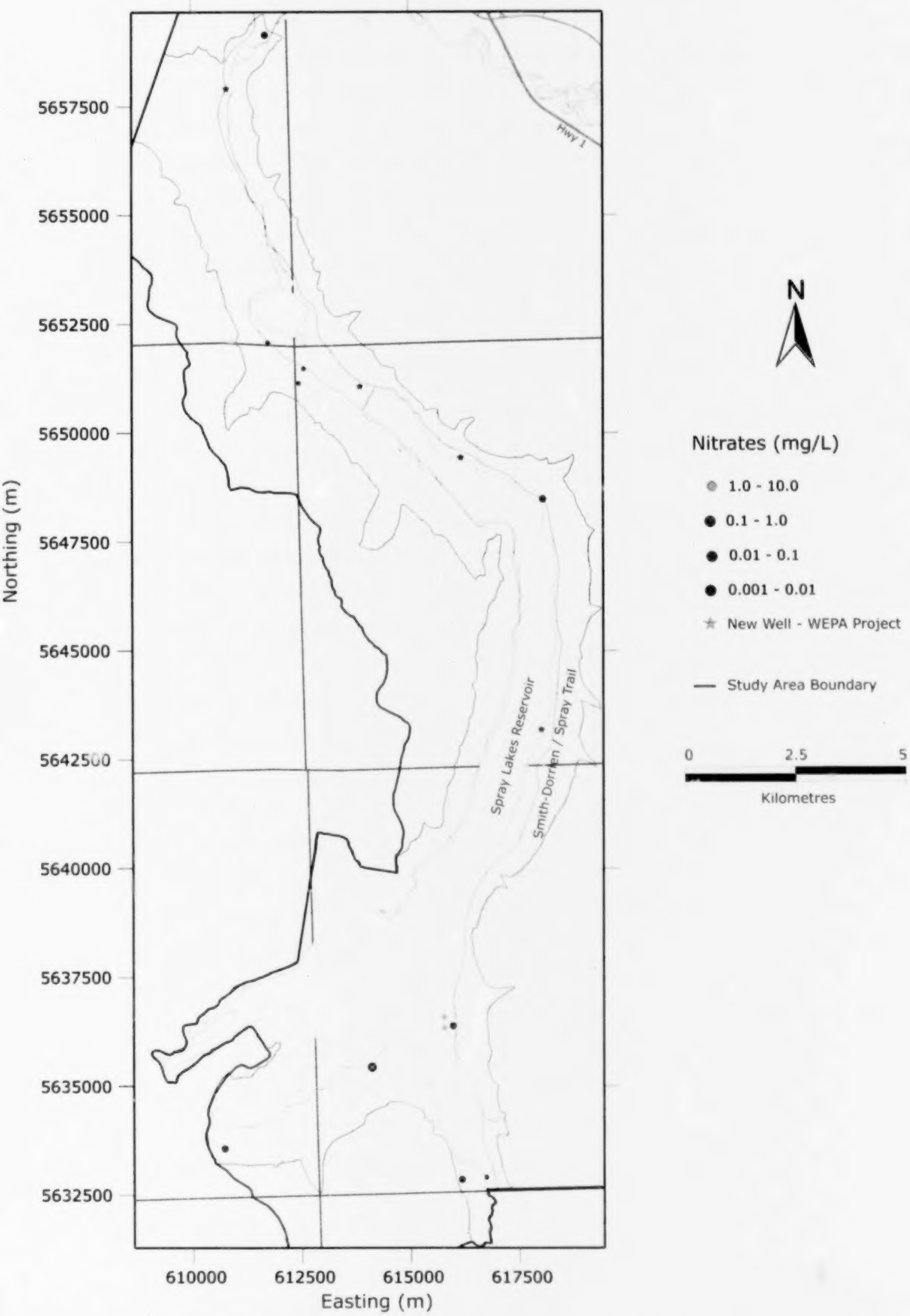

Harvie Heights
Canmore
Bow River
Hwy 1
Hwy 1A
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Lac des Arcs
Exshaw
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
Easting (m)
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Nitrates (mg/L)
10.0 - 15.0
1.0 - 10.0
0.1 - 1.0
0.01 - 0.1
0.001 - 0.01
New Well - WEPA Project
Study Area Boundary
5
0
5
Kilometres 10
N

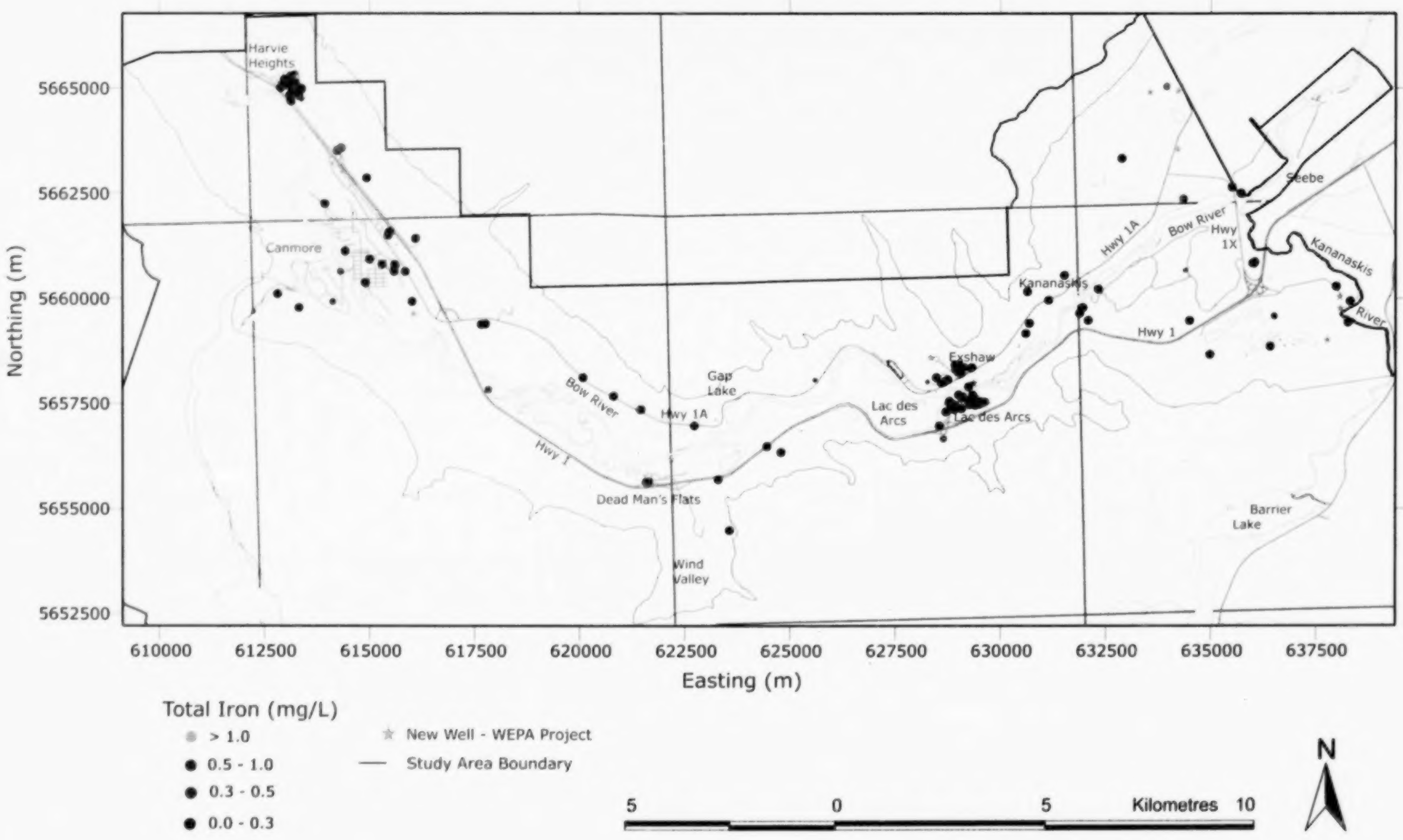
Nitrates - Kananaskis Valley



Hwy 1A
Lac des Arcs
Lac des Arcs
Hwy 1
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
N
Nitrates (mg/L)
1.0 - 10.0
0.1 - 1.0
0.01 - 0.1
0.001 - 0.01
Study Area Boundary
0
2.5
5
Kilometres
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Northing (m)
622500
625000
627500
630000
632500
635000
637500
640000
Easting (m)

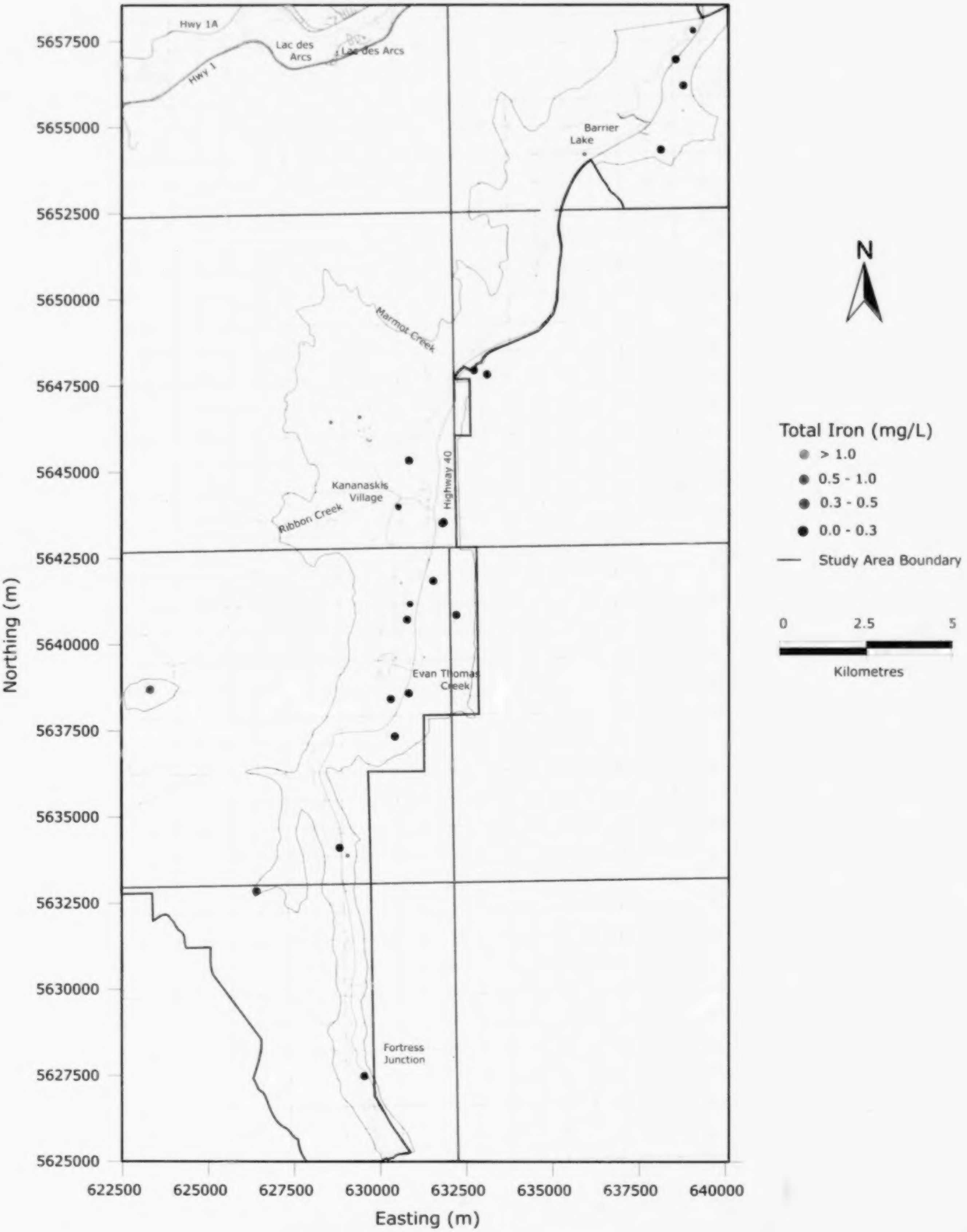
Nitrates - Spray Lakes Valley


Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Northing (m)
610000
612500
615000
617500
Easting (m)
N
Nitrates (mg/L)
● 1.0 - 10.0
● 0.1 - 1.0
● 0.01 - 0.1
● 0.001 - 0.01
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

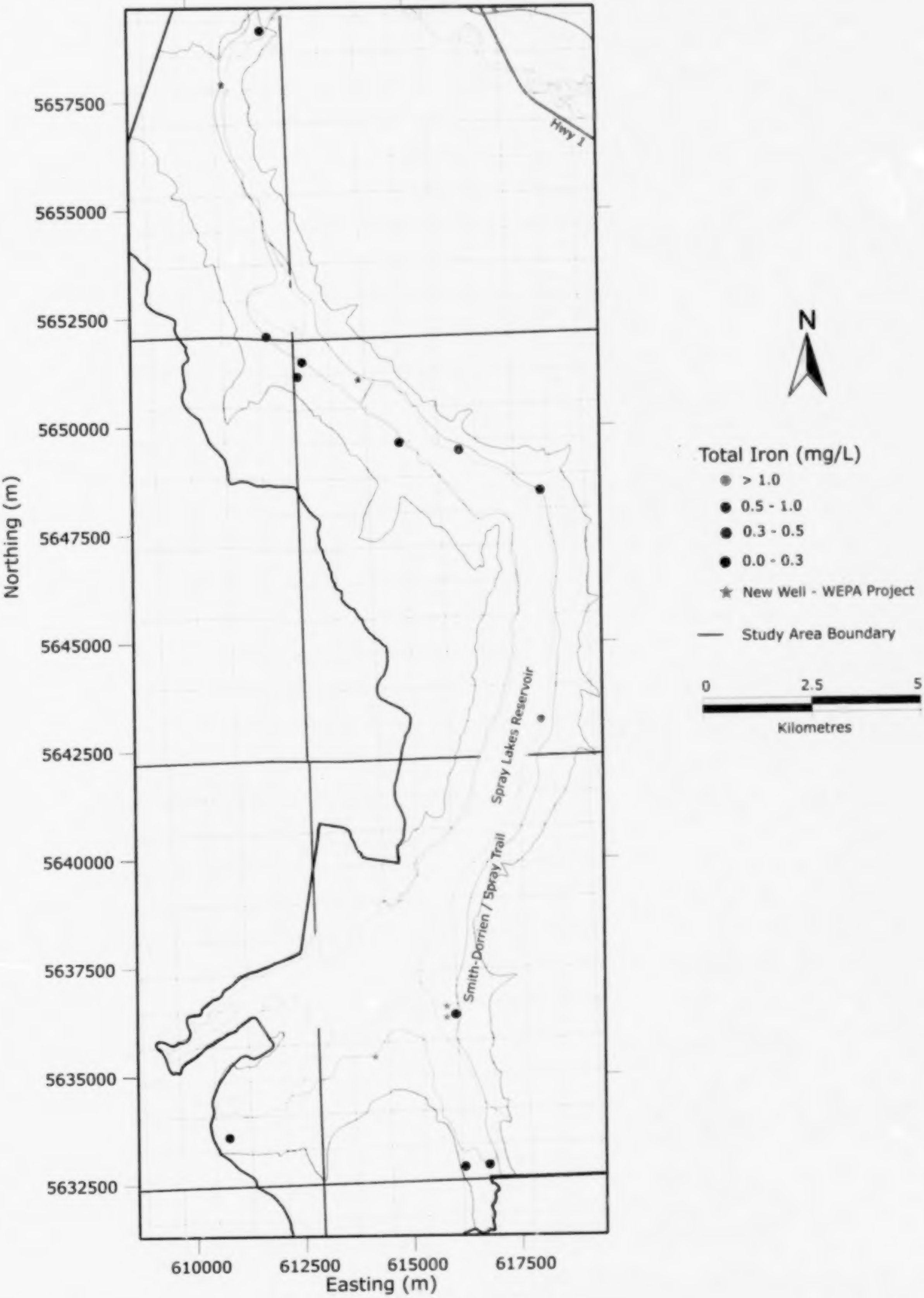

Total Iron - Bow Valley

Northing (m)
5665000
5662500
5660000
5657500
5655000
5652500
610000
612500
615000
617500
620000
622500
625000
627500
630000
632500
635000
637500
Easting (m)
Harvie Heights
Canmore
Bow River
Hwy 1
Hwy 1A
Gap Lake
Dead Man's Flats
Wind Valley
Lac des Arcs
Lac des Arcs
Exshaw
Kananaskis
Hwy 1A
Bow River
Hwy 1X
Seebe
Kananaskis River
Hwy 1
Barrier Lake
Total Iron (mg/L)
> 1.0
0.5 - 1.0
0.3 - 0.5
0.0 - 0.3
New Well - WEPA Project
Study Area Boundary
5
0
5
Kilometres 10
N

Total Iron - Kananaskis Valley


Hwy 1A
Hwy 1
Lac des Arcs
Lac des Arcs
Barrier Lake
Marmot Creek
Kananaskis Village
Ribbon Creek
Highway 40
Evan Thomas Creek
Fortress Junction
N
Total Iron (mg/L)
● > 1.0
● 0.5 - 1.0
● 0.3 - 0.5
● 0.0 - 0.3
— Study Area Boundary
0
2.5
5
Kilometres
Northing (m)
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
5630000
5627500
5625000
Easting (m)
622500
625000
627500
630000
632500
635000
637500
640000

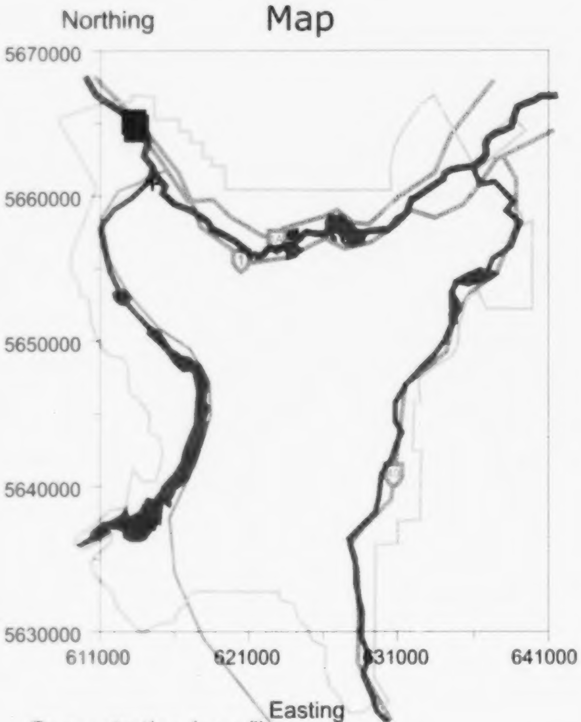
Total Iron (mg/L) - Spray Lakes Valley


Hwy 1
Spray Lakes Reservoir
Smith-Dorrien / Spray Trail
5657500
5655000
5652500
5650000
5647500
5645000
5642500
5640000
5637500
5635000
5632500
Northing (m)
610000
612500
615000
617500
Easting (m)
N
Total Iron (mg/L)
● > 1.0
● 0.5 - 1.0
● 0.3 - 0.5
● 0.0 - 0.3
★ New Well - WEPA Project
— Study Area Boundary
0
2.5
5
Kilometres

Legend:

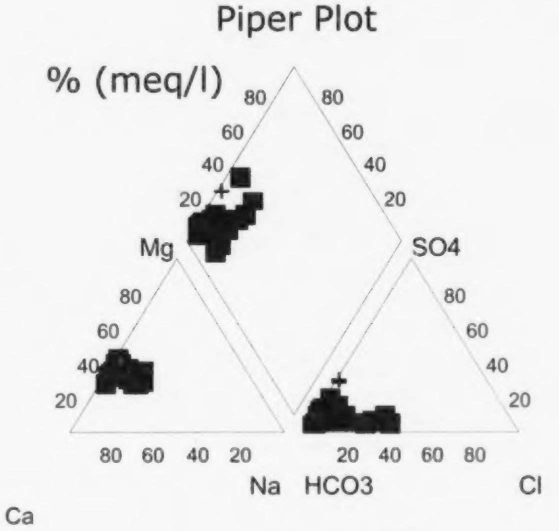
■ Harvie Heights

+ Bow River at Canmore

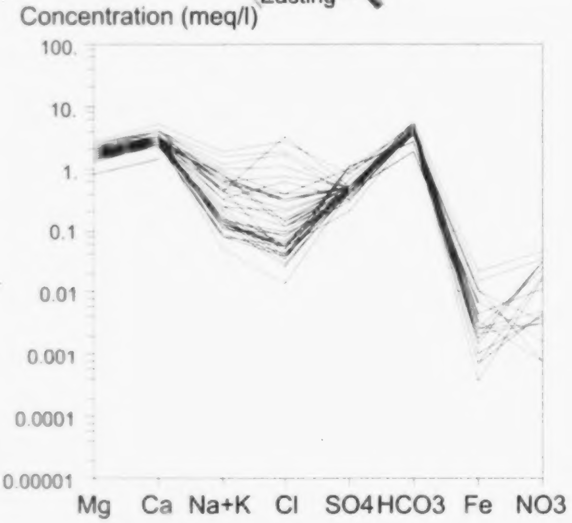


Map

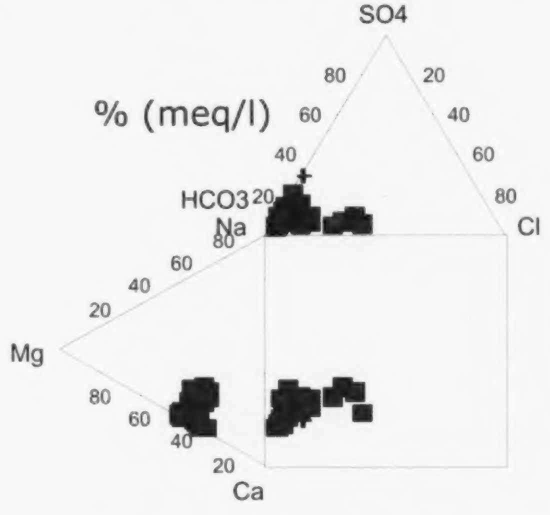
Northing
5670000
5660000
5650000
5640000
5630000
611000
621000
631000
641000
Easting



Piper Plot



Schoeller Plot



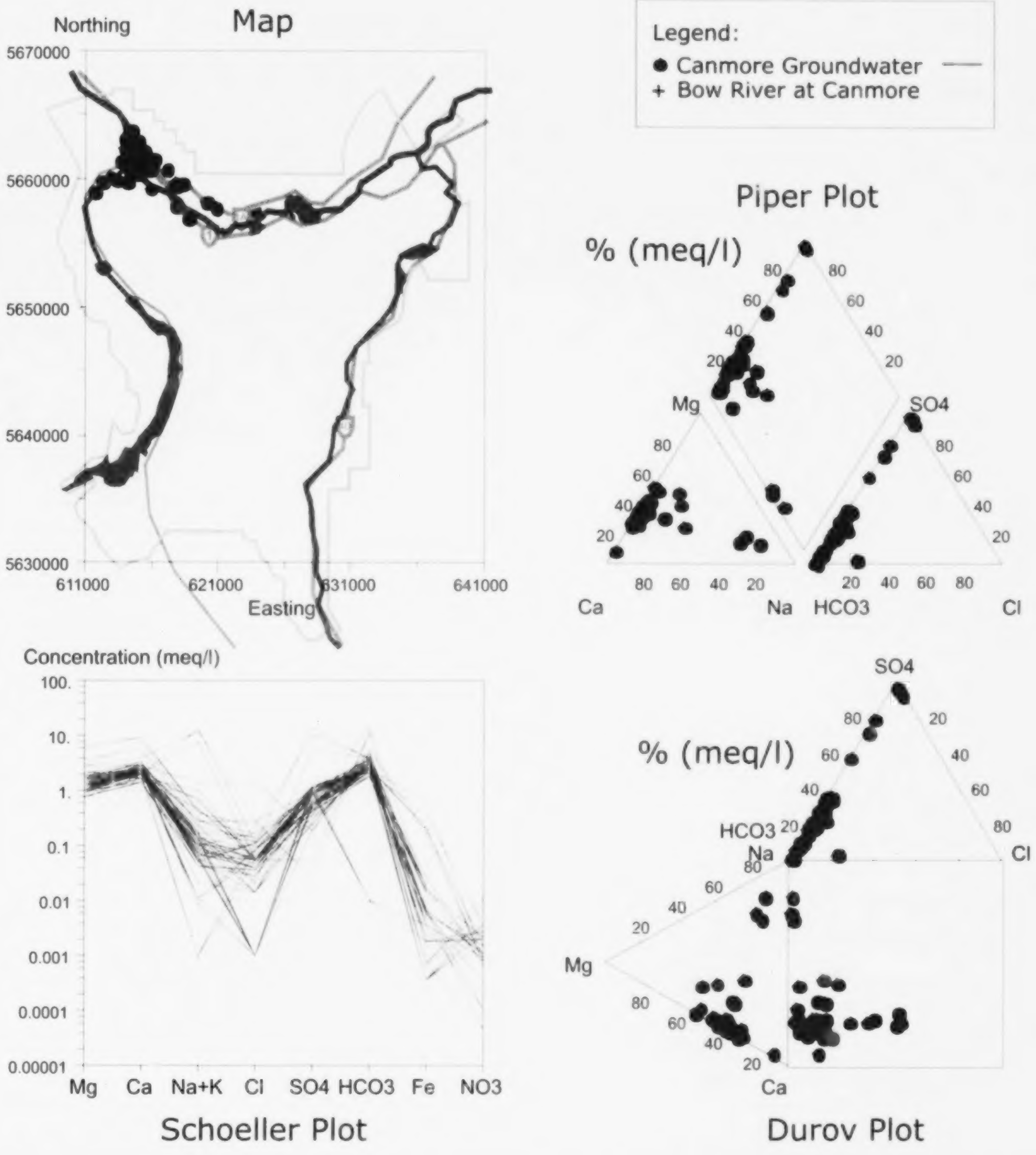
Durov Plot

Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Harvie Heights

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



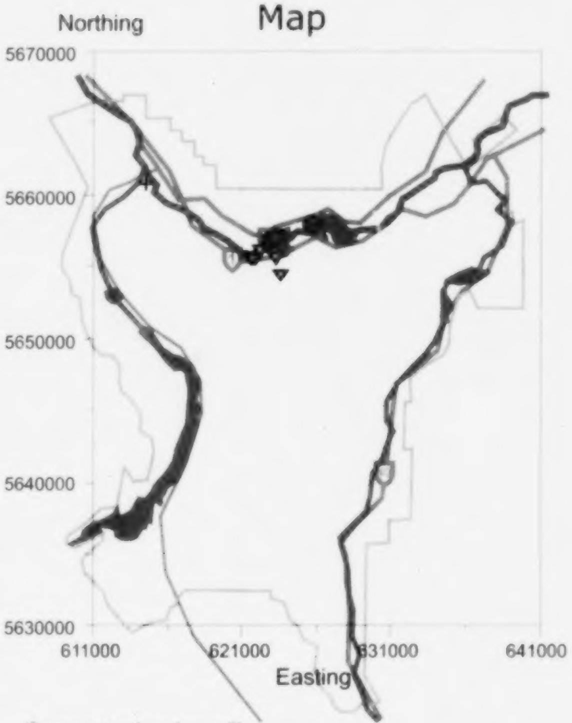
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Canmore

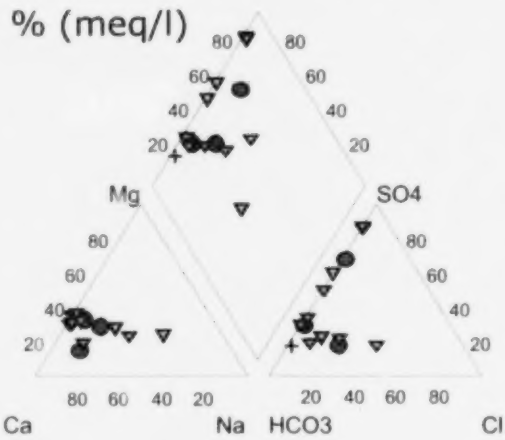
Graphical Comparison of Groundwater Samples

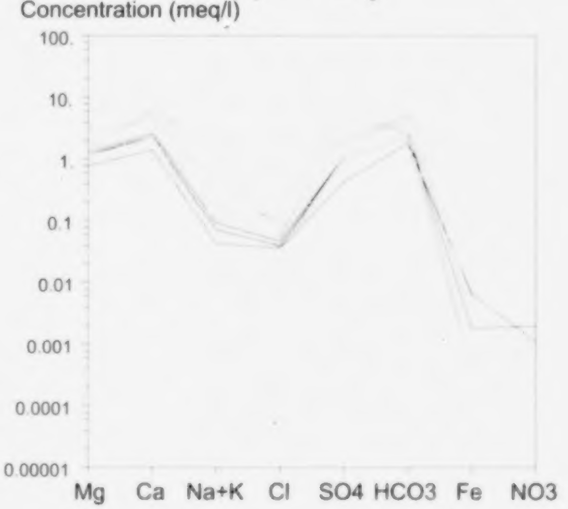
Alberta Environment - Hydrogeology, 2002


Map
Northing
5670000
5660000
5650000
5640000
5630000
611000
621000
631000
641000
Easting

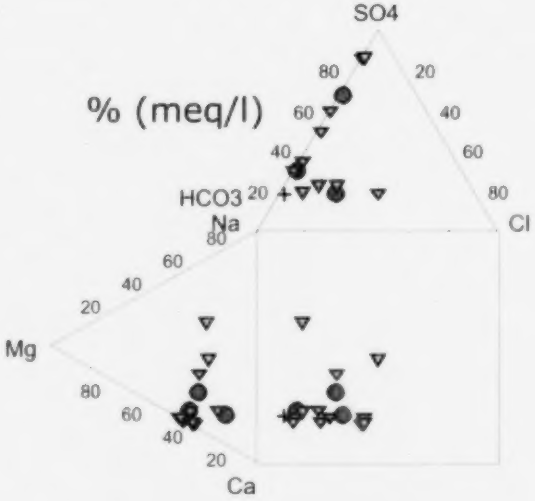
Legend:
- ▽ Dead Man's Flats
- ● Gap
- + Bow River at Canmore

Piper Plot





Schoeller Plot



Durov Plot

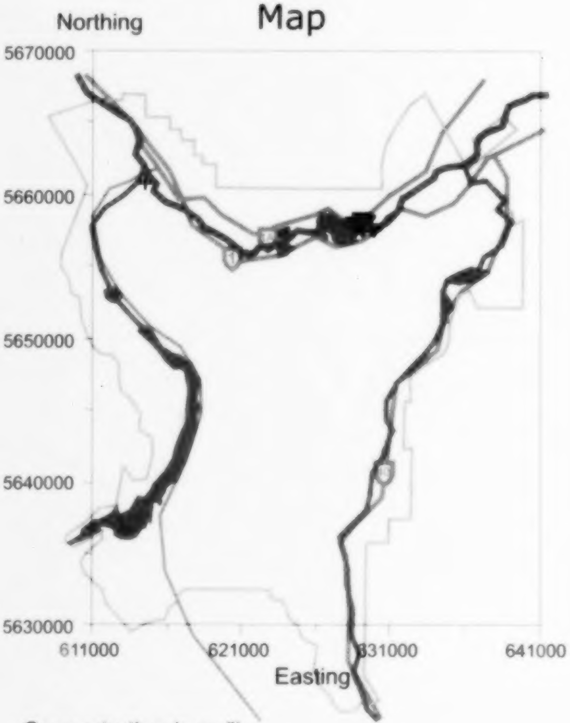
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

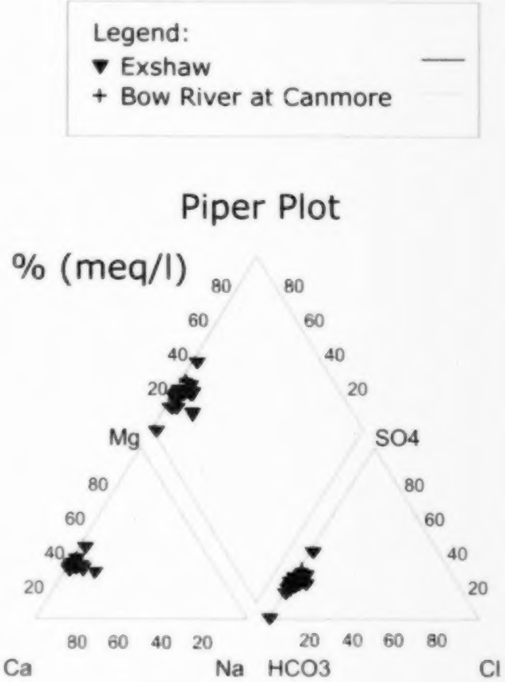
Alberta
ENVIRONMENT

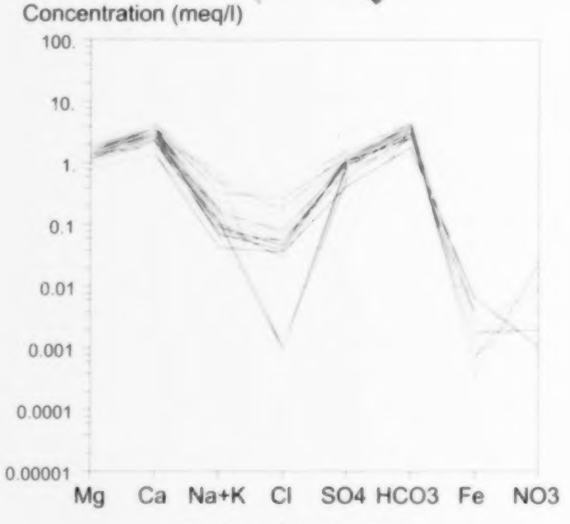
Dead Man's Flats and Gap-north of river

Graphical Comparison of Groundwater Samples

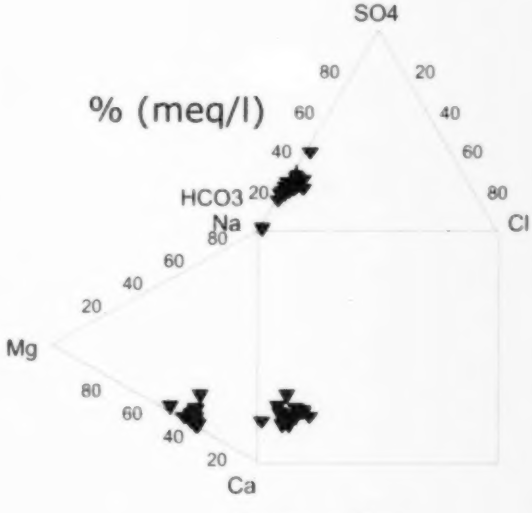
Alberta Environment - Hydrogeology, 2002


Map
Northing
5670000
5660000
5650000
5640000
5630000
611000
621000
631000
641000
Easting





Schoeller Plot



Durov Plot

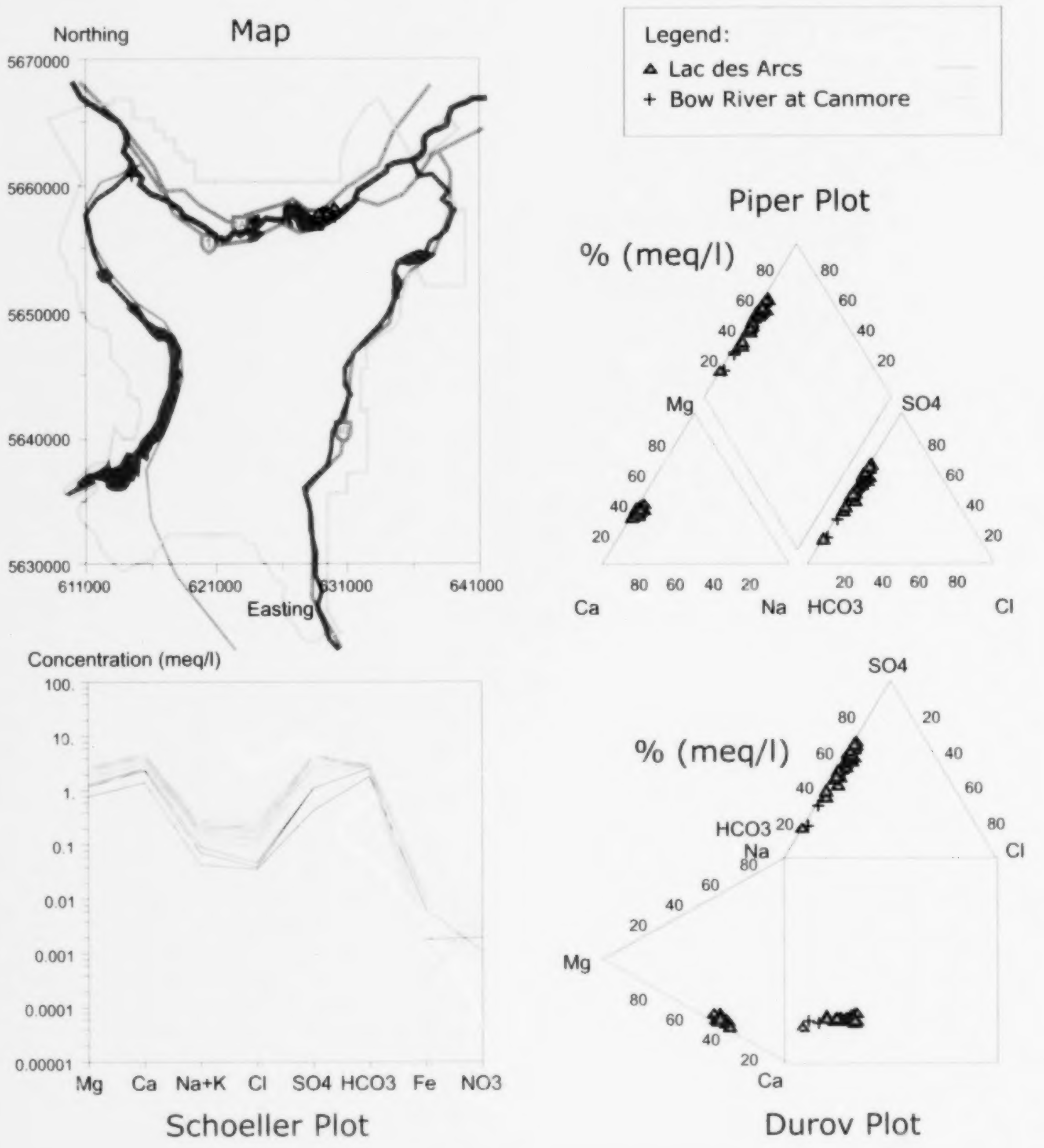
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta ENVIRONMENT

Exshaw

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



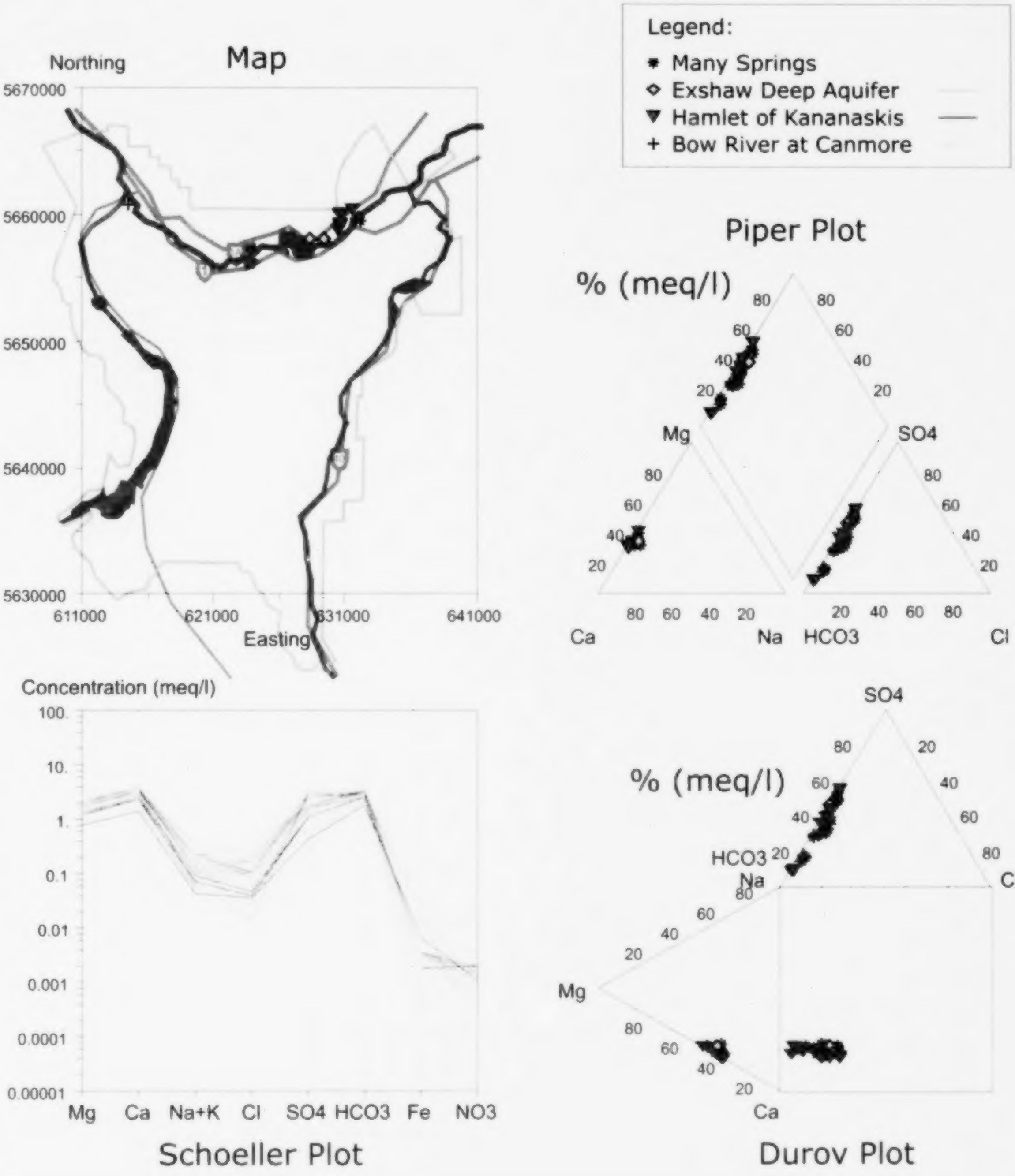
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta ENVIRONMENT

Lac des Arcs

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



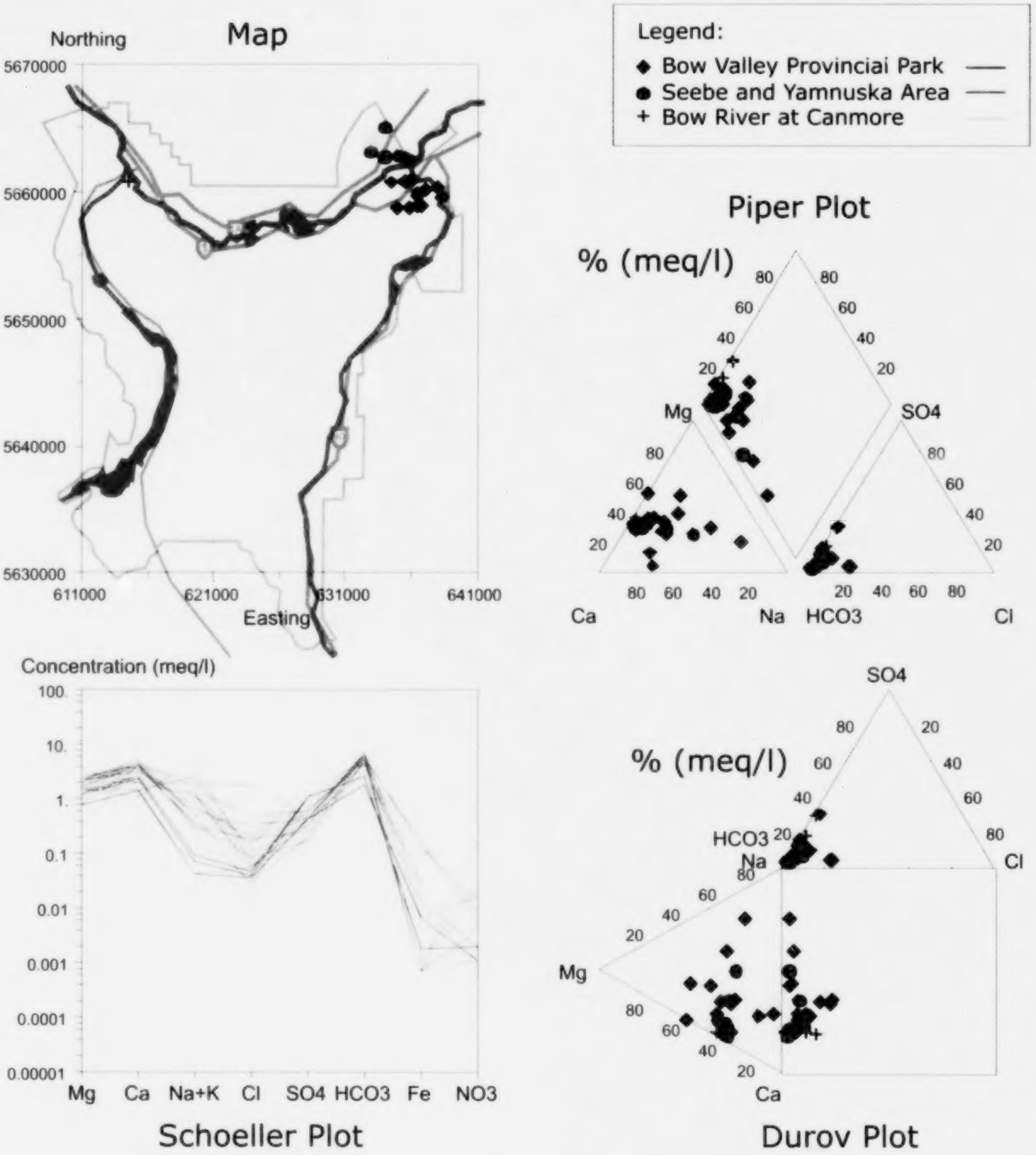
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Many springs and Vicinity

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



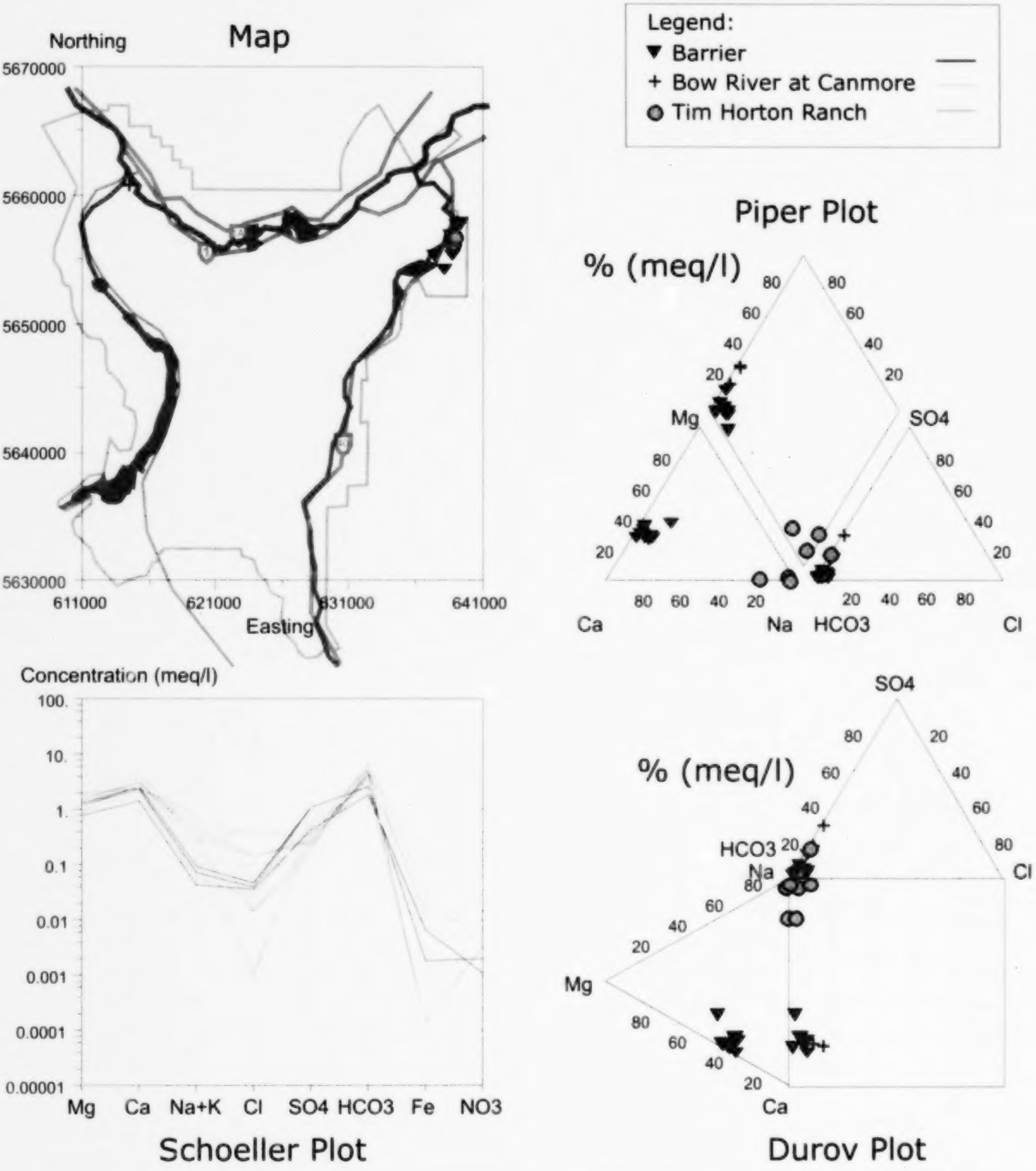
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Seebe - Bow Valley Park District

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

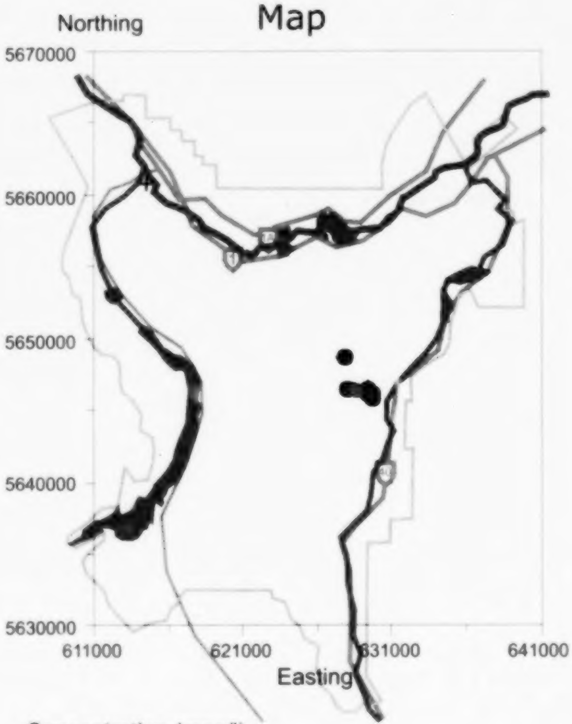
Alberta
ENVIRONMENT

Lower Kananaskis Valley

Graphical Comparison of Groundwater Samples

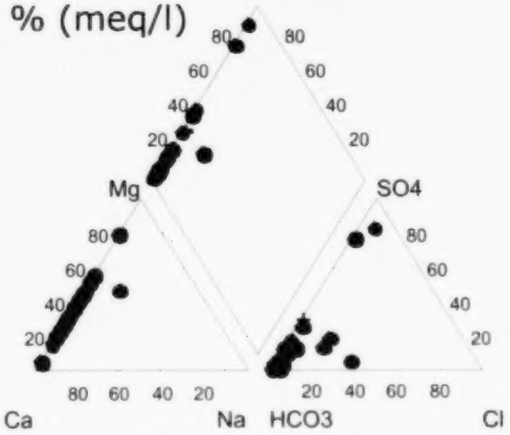
Alberta Environment - Hydrogeology, 2002

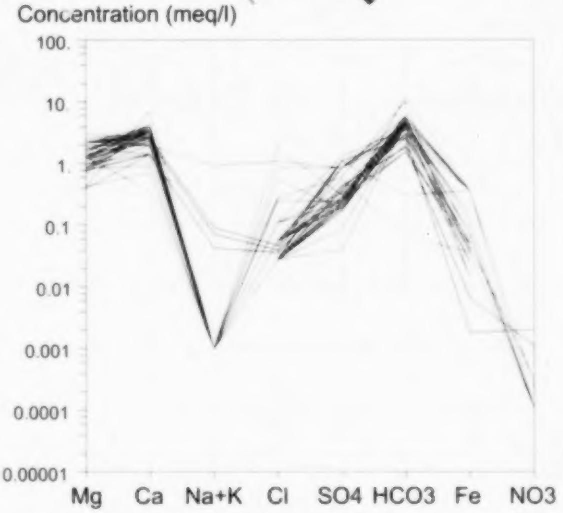
Map


Northing
5670000
5660000
5650000
5640000
5630000
611000
621000
631000
641000
Easting

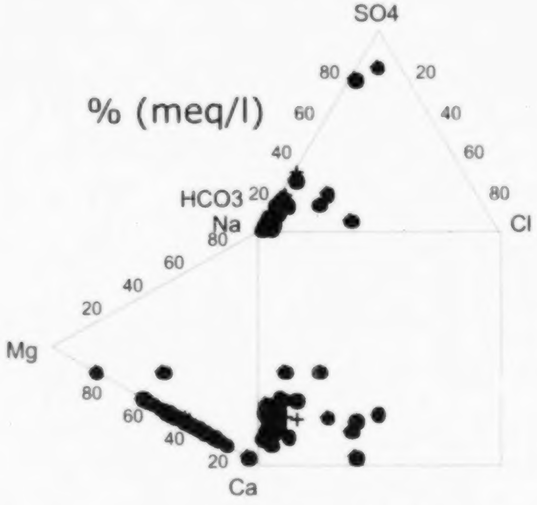
Legend:
● Marmot Creek Basin
+ Bow River at Canmore

Piper Plot





Schoeller Plot



Durov Plot

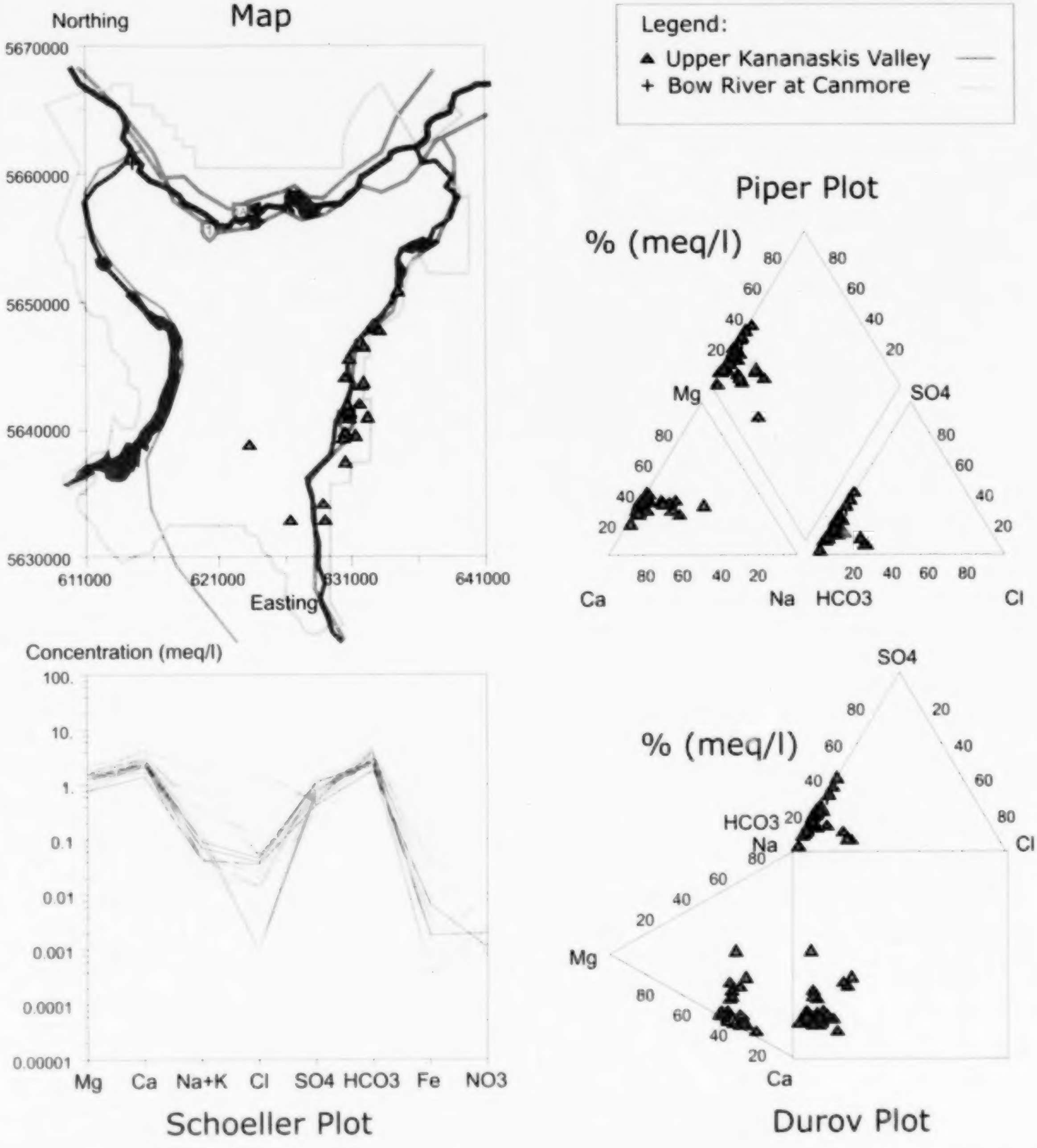
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Marmot Creek Experimental Basin

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



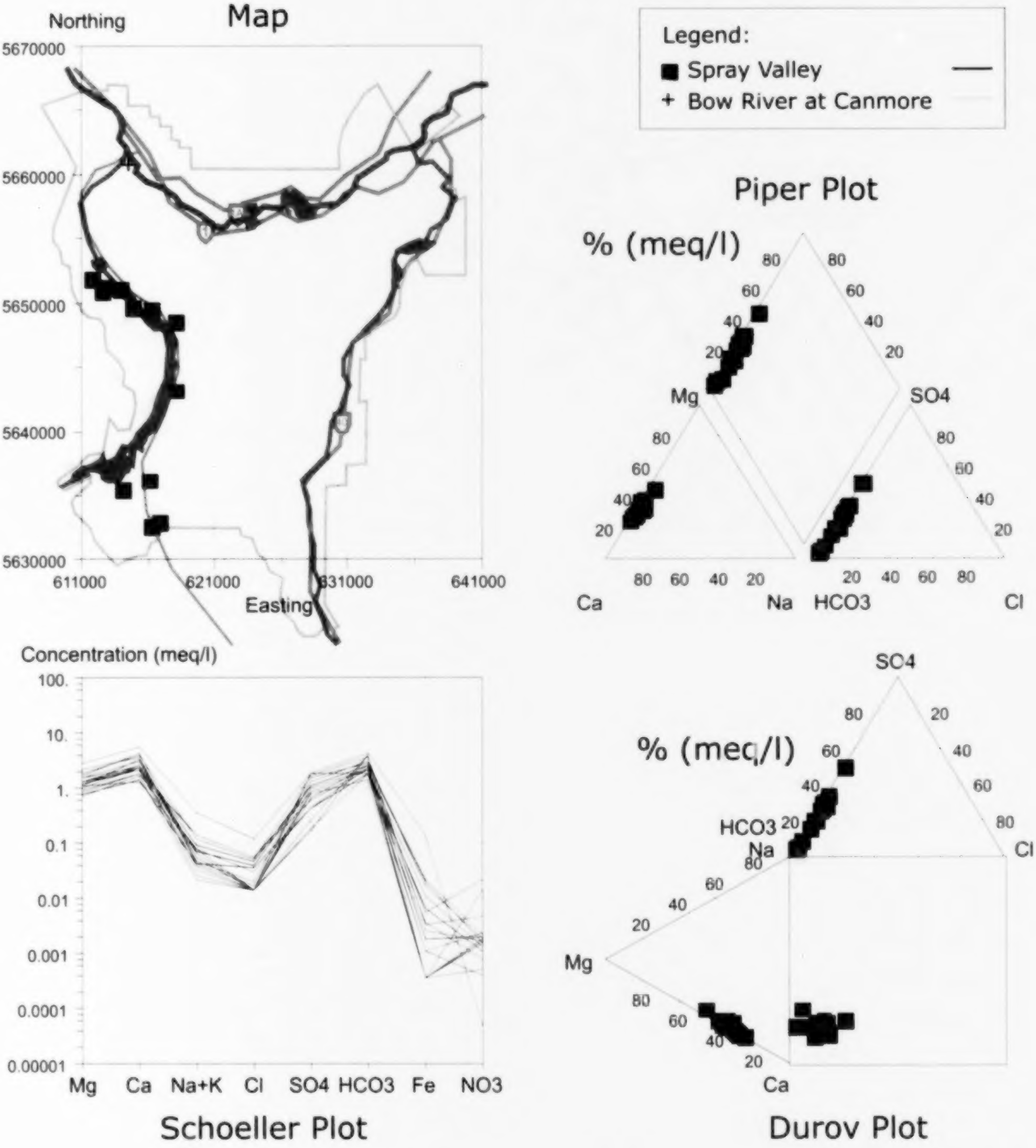
Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Upper Kananaskis Valley

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002



Bow Valley - Canmore Corridor and Northwestern Kananaskis Country

Alberta
ENVIRONMENT

Spray Lakes Valley

Graphical Comparison of Groundwater Samples

Alberta Environment - Hydrogeology, 2002

Well Water Analysis Guide

Major Cations	**Aesthetic Objective mg/L**	**Effects**
Calcium	200	Hard water; essential nutritional element
Magnesium	150	Hard water; laxative effect; nutritional element
Potassium	-	
Sodium	200	May raise blood pressure
Iron	0.3	poor taste, red staining of laundry and fixtures
Manganese	0.05	poor taste, black staining of laundry and fixtures

Major Anions	**Aesthetic Objective mg/L**	**Effects**
Bicarbonate	700	Hard water
Carbonate	-	
Chloride	250	corrosive
Fluoride	1.5 **maximum**	Essential nutrient; excess can cause dental fluorosis
Hydroxide	-	
Nitrate	45 **maximum***	"blue baby" syndrome in infants
Sulphate	500	Laxative effect

*eqivalent to 10 mg/L nitrate-nitrogen

Misc. Inorganics	**Aesthetic Objective**	**Effects**
Turbidity	8 TU	Affects taste, odour
Conductivity	1500 mS/cm	Indicator of Total Dissolved Solids
pH	6.5-8.5	<6.5 – corrosion of pipes; >8.5 scaling of pipes
Alkalinity	500 mg/L	Scaling of pipes; excessive soap consumption
Hardness	500 mg/L	Scaling of pipes; excessive soap consumption
Total Dissolved Solids	500 mg/L*	Affects taste

*1000 mg/L is widely accepted as the limit in rural Alberta

Unless otherwise stated, maximums and objectives are based on Health Canada: Guidelines for Canadian Drinking Water Quality, 2001.

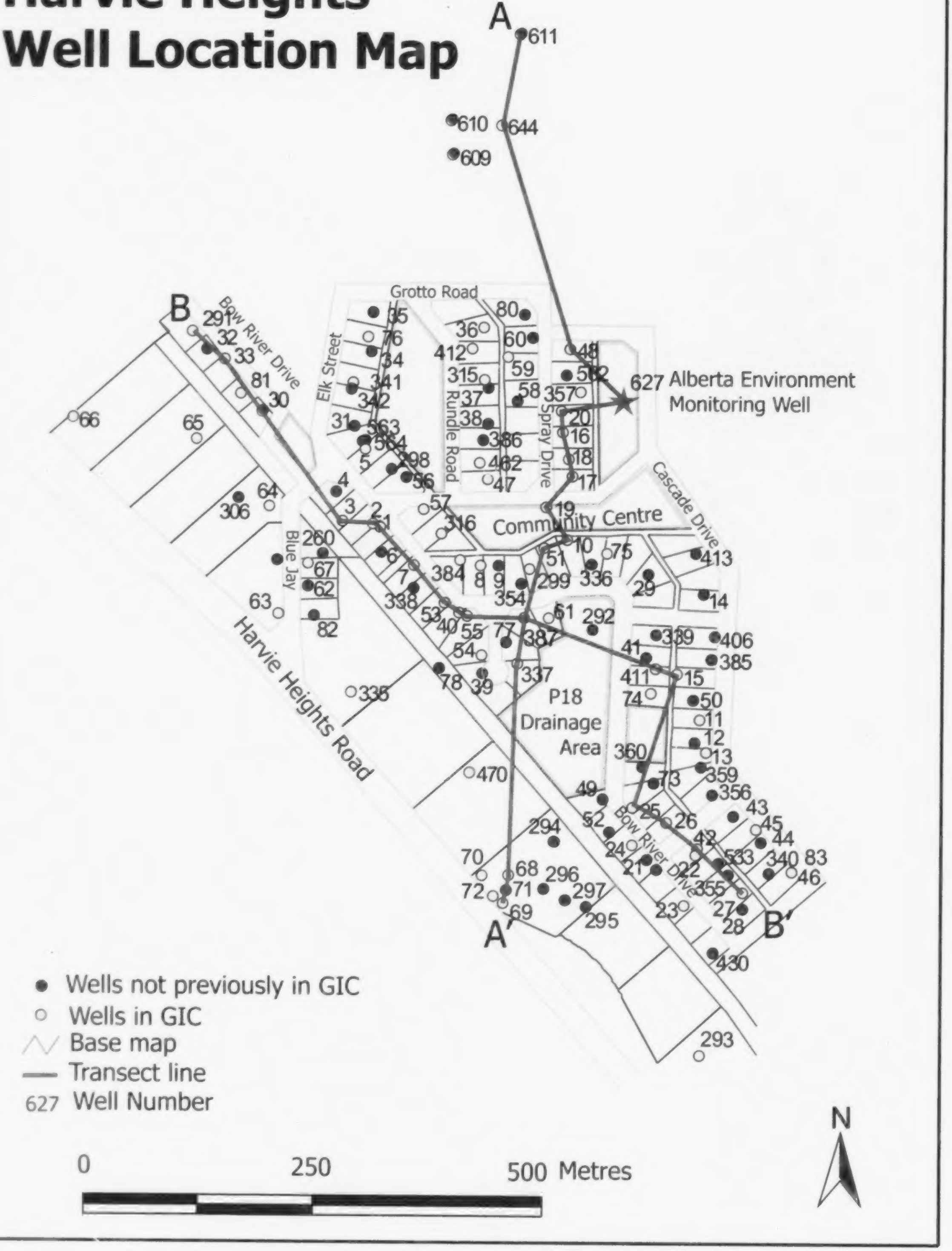
Trace Elements	**Canadian Maximum (mg/L)**	**Aesthetic Objective (mg/L)**	**USA – EPA Maximum (mg/L)**	**Potential Health Effects**
Aluminum			0.2	Linked with Alzheimer's disease
Antimony			0.006	Affects blood cholesterol and glucose levels
Arsenic	0.025		0.05	Carcinogenic; damage to skin and circulatory system
Barium	1.0		2.0	Increased blood pressure
Berylium			0.004	Intestinal lesions
Boron	5			Affects central nervous system
Cadmium	0.005		0.005	Essential nutritional element; excess may cause kidney damage
Chromium	0.05		0.1	Essential nutritional element; excess exposure may lead to allergic dermatitis
Cobalt				In vitamin B_{12}
Copper		1.0	1.3	Essential nutritional element; kidney damage in prolonged excess exposure
Iron		0.3		Essential nutritional element. In large quantities imparts bad taste to water, stains laundry and fixtures.
Lead	0.010		0.015	Cumulative general poison
Lithium				No guideline; readily flushed from body
Manganese		0.05	0.05	Essential nutritional element; In large quantities impart bad taste to water, stains laundry and fixtures.
Mercury	0.001		0.002	Cumulative general poison
Molybdenum				Essential nutritional element
Nickel				Essential nutritional element
Phosphorus				Essential nutritional element
Potassium				Essential nutritional element
Selenium	0.01		0.05	Essential nutritional element. excess causes hair loss, numbness of extremities and circulation problems.
Silicon				Essential nutritional element
Silver			0.10	Non-essential nutritional element; toxic in extreme doses
Sodium		200		Essential nutritional element; large amounts can raise blood pressure.
Strontium				No guideline; rare
Sulphur				No guideline; common in foods
Thallium			0.002	Hair loss, kidney, blood, intestine and liver problems.
Tin				Essential nutritional element
Titanium				No guideline; rare
Uranium	0.1			Kidney damage
Vanadium				Essential nutritional element
Zinc		5.0	5.0	Essential nutritional element; imparts bad taste to water.
Zirconium				No guideline; rare

Appendix C

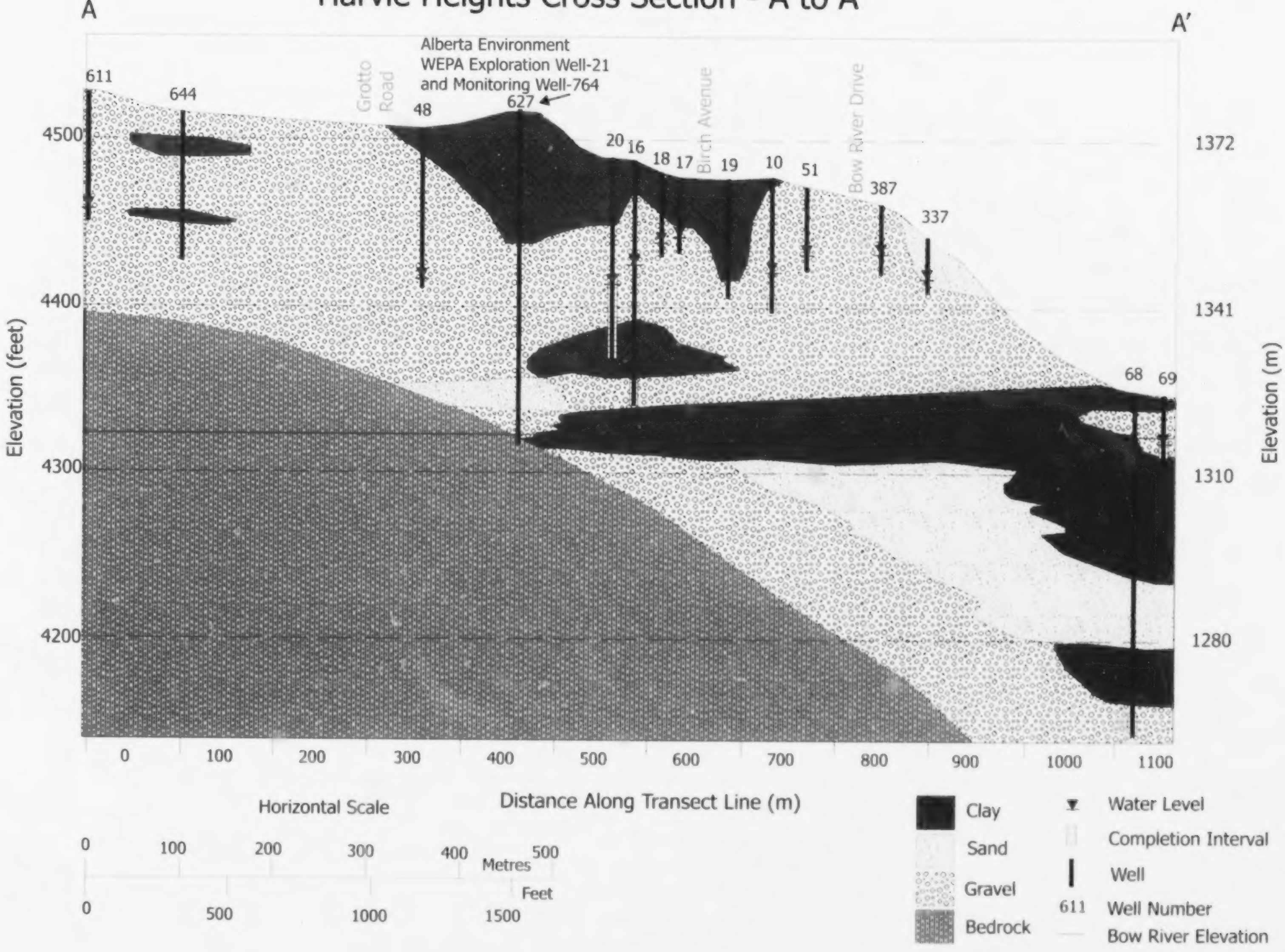
Cross Sections and Well Locations

Harvie Heights – Well Location Map
Harvie Heights – Cross Section A-A′
Harvie Heights – Cross Section B-B′
Canmore – Well Location Map
Canmore – Cross Section C-C′
Dead Man's Flats – Well Location Map
Dead Man's Flats – Cross Section F-F′
Exshaw – Lac des Arcs – Well Location Map
Exshaw – Lac des Arcs – Cross Section D-D′
Exshaw – Lac des Arcs – Cross Section D-E′
Lac des Arcs – Cross Section E-E′
Seebe - Well Location Map
Seebe – Cross Section G-G′
Kananaskis – Well Location Map
Kananaskis – Cross Section H-H′
Bow Valley – Well Location Map
Bow Valley – Cross Section I-I′

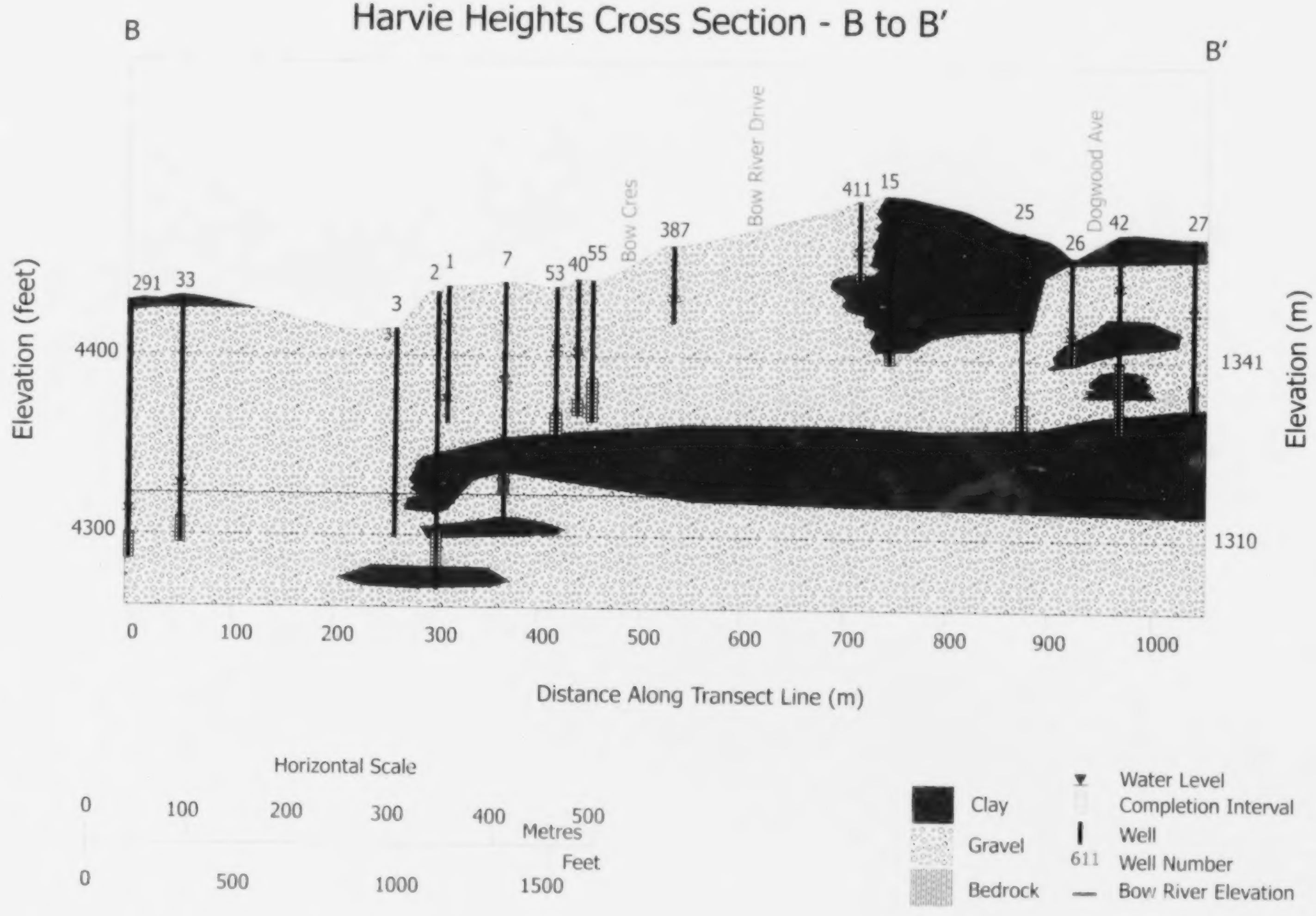
Harvie Heights Well Location Map

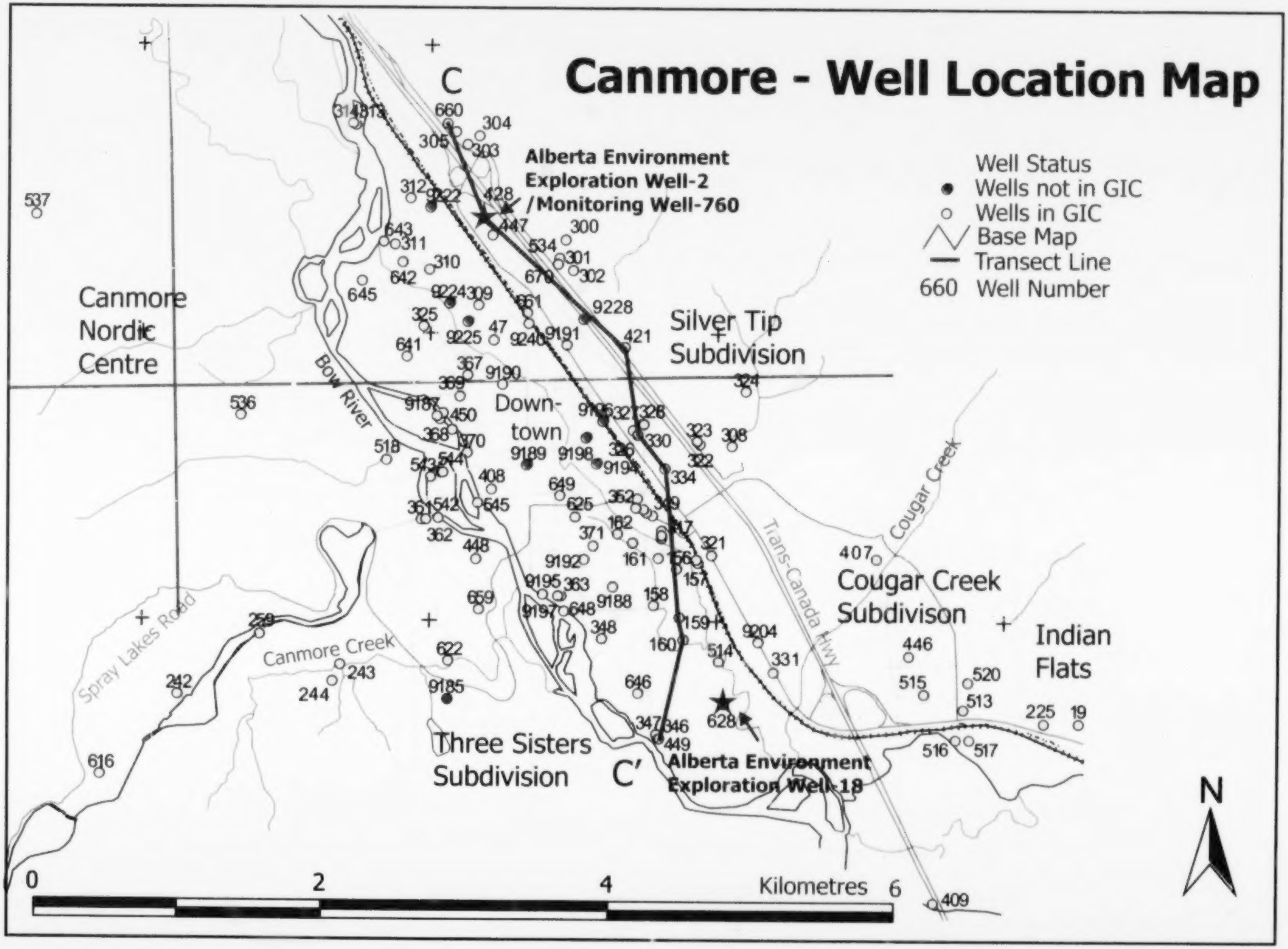

A
A′
B
B′
Grotto Road
Elk Street
Rundle Road
Spray Drive
Bow River Drive
Cascade Drive
Blue Jay
Harvie Heights Road
Community Centre
P18 Drainage Area
627 Alberta Environment Monitoring Well
611
610
644
609
Wells not previously in GIC
Wells in GIC
Base map
Transect line
627 Well Number
0
250
500 Metres
N

Harvie Heights Cross Section - A to A′

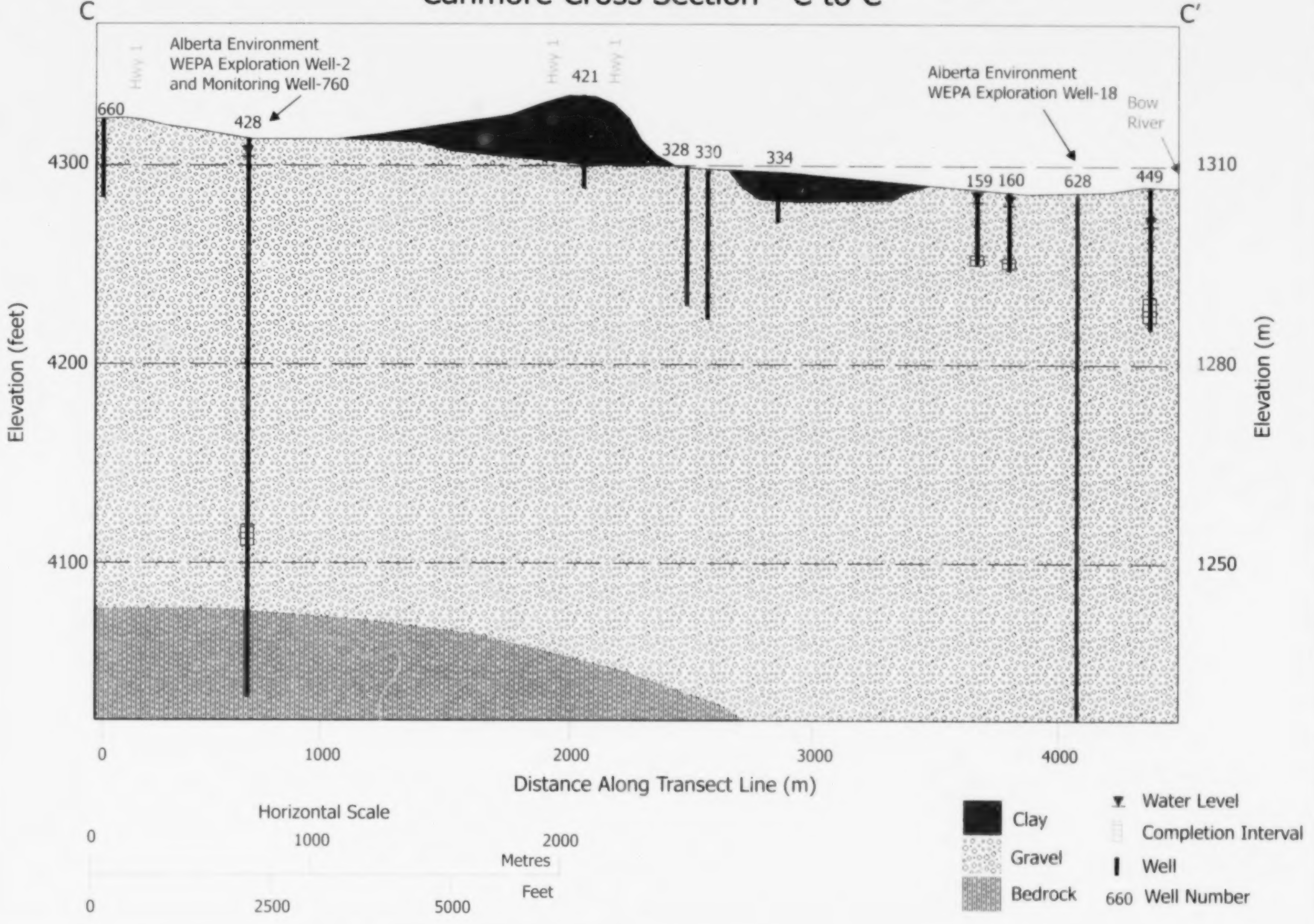

A
A′
Alberta Environment
WEPA Exploration Well-21
and Monitoring Well-764
611
644
Grotto Road
48
627
20
16
18
17
Birch Avenue
19
10
51
Bow River Drive
387
337
68
69
Elevation (feet)
4500
4400
4300
4200
Elevation (m)
1372
1341
1310
1280
0
100
200
300
400
500
600
700
800
900
1000
1100
Distance Along Transect Line (m)
Horizontal Scale
0
100
200
300
400
500
Metres
0
500
1000
1500
Feet
Clay
Sand
Gravel
Bedrock
Water Level
Completion Interval
Well
611 Well Number
Bow River Elevation

Harvie Heights Cross Section - B to B′

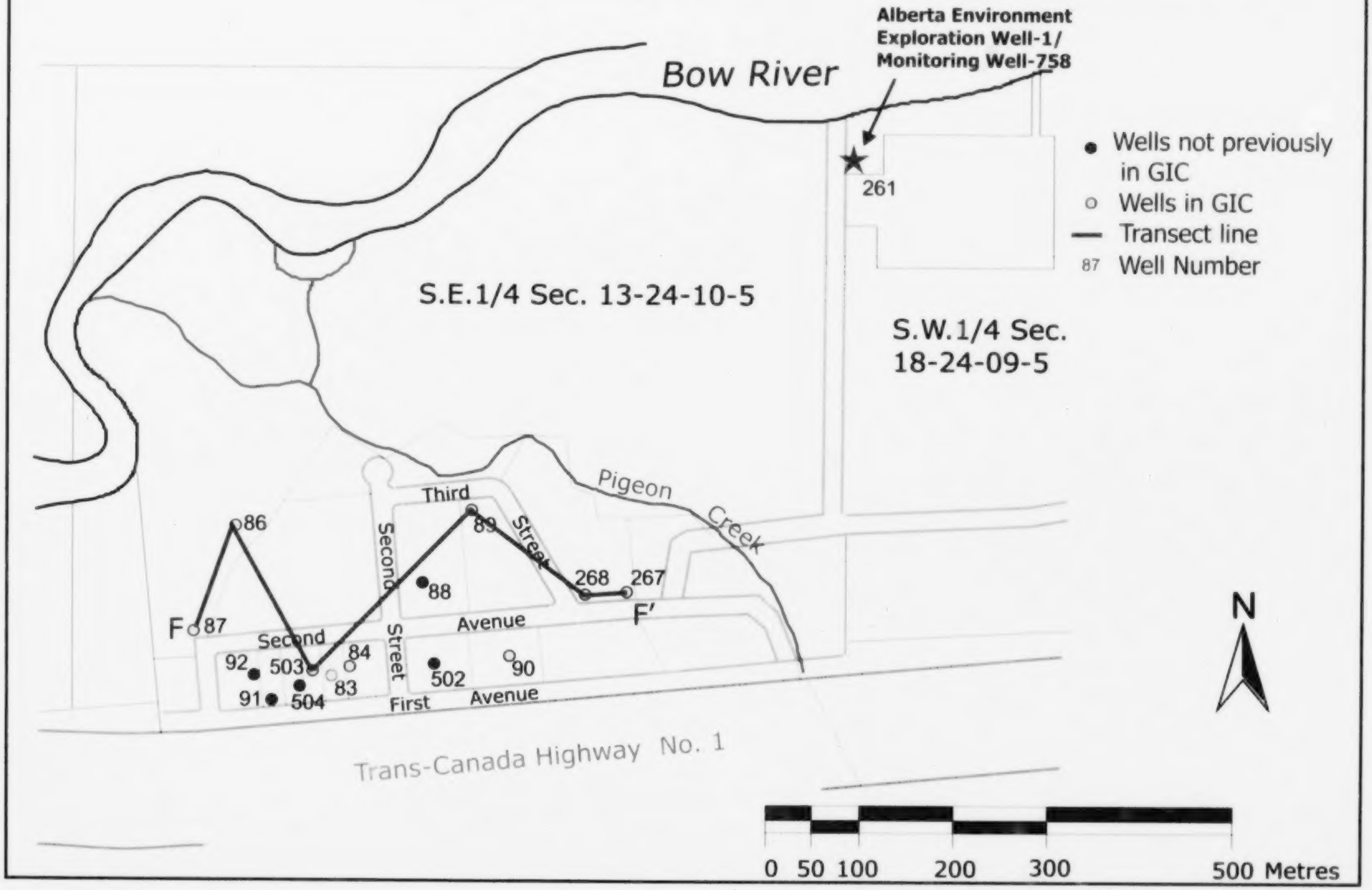

B
B′
291
33
3
2
1
7
53
40
55
Bow Cres
387
Bow River Drive
411
15
25
26
Dogwood Ave
42
27
Elevation (feet)
4400
4300
Elevation (m)
1341
1310
0
100
200
300
400
500
600
700
800
900
1000
Distance Along Transect Line (m)
Horizontal Scale
0
100
200
300
400
500
Metres
0
500
1000
1500
Feet
Clay
Gravel
Bedrock
Water Level
Completion Interval
Well
611 Well Number
Bow River Elevation


Canmore - Well Location Map
Well Status
● Wells not in GIC
○ Wells in GIC
Base Map
Transect Line
660 Well Number
C
C′
Alberta Environment Exploration Well-2 /Monitoring Well-760
Alberta Environment Exploration Well-18
Canmore Nordic Centre
Silver Tip Subdivision
Down-town
Cougar Creek Subdivison
Indian Flats
Three Sisters Subdivision
Bow River
Cougar Creek
Trans-Canada Hwy
Canmore Creek
Spray Lakes Road
N
0
2
4
6
Kilometres
537
536
616
242
259
244
243
622
9185
660
304
305
303
312
9222
428
447
300
534
301
302
670
643
311
310
642
645
9224
309
325
641
9225
47
9240
9191
661
9228
421
367
9190
369
324
9187
450
9196
321
328
368
370
518
543
544
9189
9198
326
330
323
308
9194
334
322
408
649
361
542
545
625
352
349
362
448
371
182
347
321
9192
161
156
157
659
9195
363
9188
158
407
9197
648
348
159
9204
160
514
331
446
646
628
515
520
513
225
19
347
346
449
516
517
409

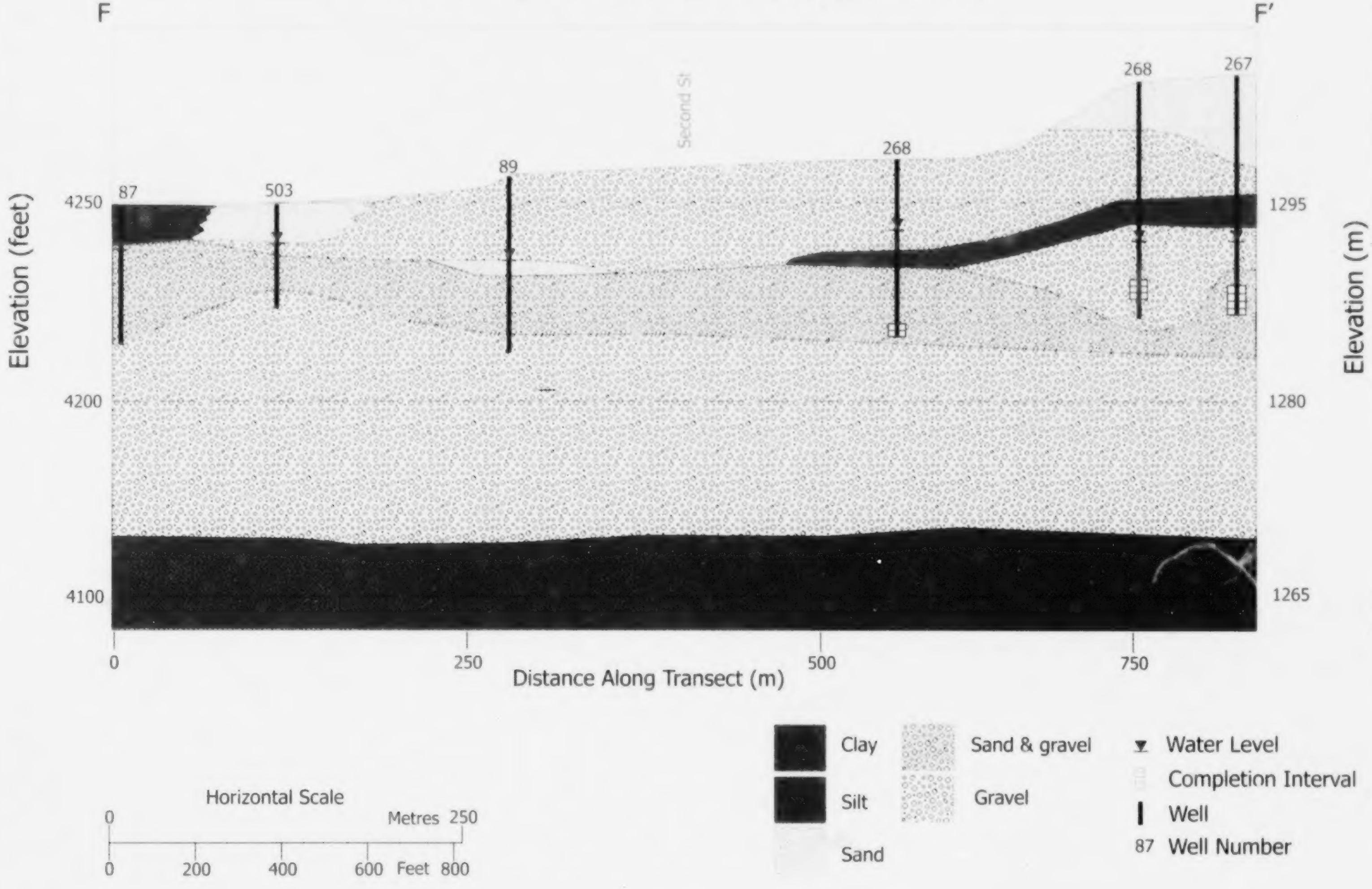
Canmore Cross Section - C to C′


C
C′
Hwy 1
Alberta Environment
WEPA Exploration Well-2
and Monitoring Well-760
Hwy 1
421
Hwy 1
Alberta Environment
WEPA Exploration Well-18
Bow
River
660
428
328
330
334
159
160
628
449
4300
4200
4100
Elevation (feet)
1310
1280
1250
Elevation (m)
0
1000
2000
3000
4000
Distance Along Transect Line (m)
Horizontal Scale
0
1000
2000
Metres
0
2500
5000
Feet
Clay
Gravel
Bedrock
Water Level
Completion Interval
Well
660 Well Number

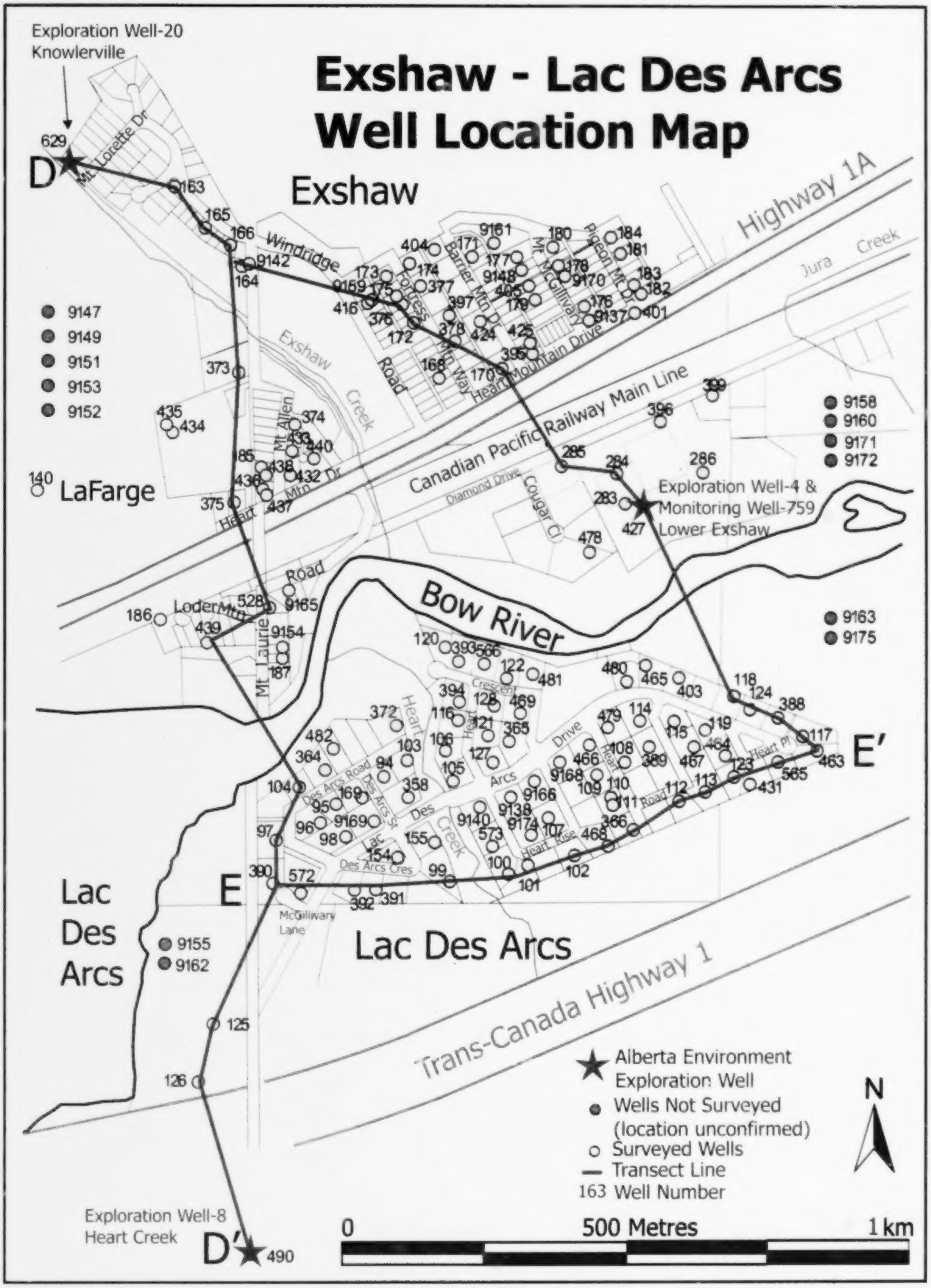
Dead Man's Flats Well Location Map


Alberta Environment
Exploration Well-1/
Monitoring Well-758
Bow River
261
● Wells not previously in GIC
○ Wells in GIC
— Transect line
87 Well Number
S.E.1/4 Sec. 13-24-10-5
S.W.1/4 Sec. 18-24-09-5
Pigeon Creek
Third Street
Second Street
Second Avenue
First Avenue
Avenue
Street
F
F'
86
87
92
503
91
504
84
83
88
89
268
267
502
90
Trans-Canada Highway No. 1
N
0 50 100 200 300 500 Metres

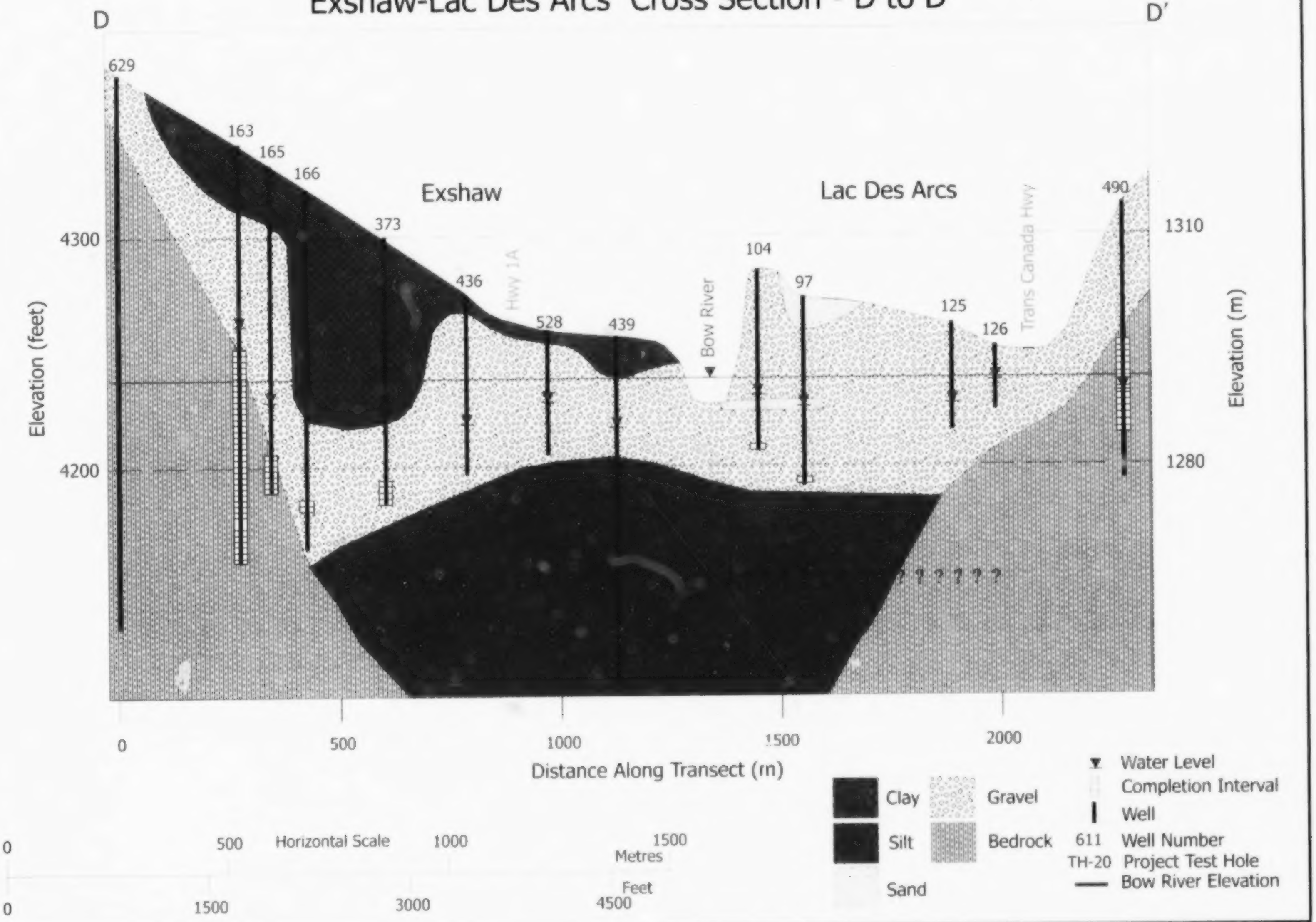
Dead Man’s Flats Cross Section - F to F′

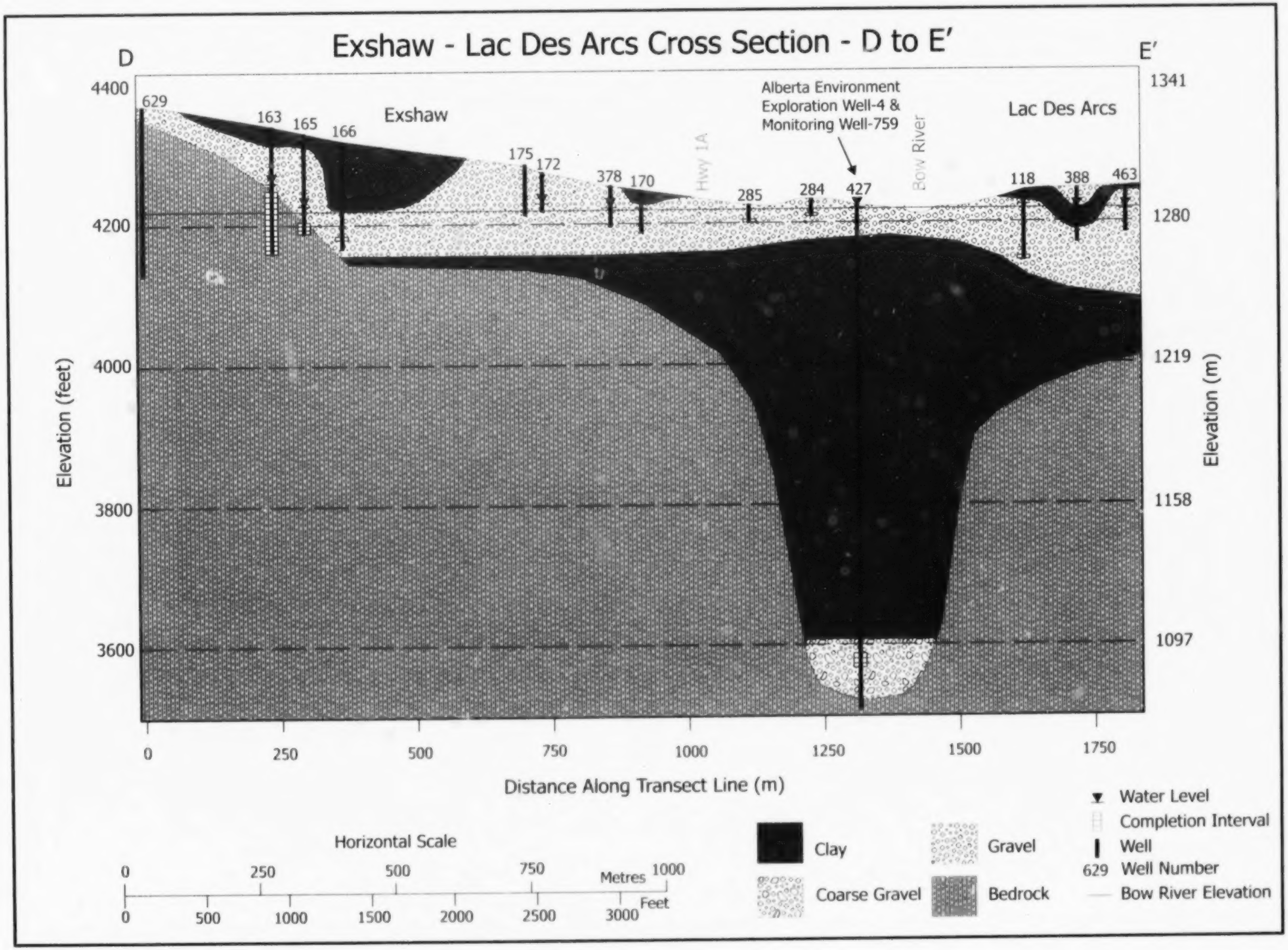


F
F′
Second St
87
503
89
268
268
267
Elevation (feet)
4250
4200
4100
Elevation (m)
1295
1280
1265
0
250
500
750
Distance Along Transect (m)
Clay
Silt
Sand
Sand & gravel
Gravel
Water Level
Completion Interval
Well
87 Well Number
Horizontal Scale
0
Metres 250
0
200
400
600
Feet 800


Exshaw - Lac Des Arcs
Well Location Map
Exploration Well-20
Knowlerville
629
D
Mt. Lorette Dr
163
165
166
Windridge
9142
164
Exshaw
Highway 1A
Jura Creek
9161
404
171
180
184
181
Barrier Mtn Dr
Mt McGillivray
Pigeon Mt Cr
177
178
173
174
377
9148
9170
183
182
9159
175
Fortress
405
179
416
376
397
176
9137
401
172
378
424
425
Exshaw Creek
Road
168
Mtn Way
395
170
Heart Mountain Drive
373
Canadian Pacific Railway Main Line
399
396
9147
9149
9151
9153
9152
435
434
374
Mt Allen
433
440
85
438
432
436
Mtn Dr
437
375
Heart
140
LaFarge
285
284
286
Diamond Drive
Cougar Cl
Exploration Well-4 &
Monitoring Well-759
Lower Exshaw
283
427
478
9158
9160
9171
9172
Road
LoderMtn
528
9165
186
439
9154
187
Mt Laurie
Bow River
9163
9175
120
393
566
122
481
480
465
403
118
124
388
394
Crescent
128
469
116
121
365
479
114
115
119
117
E′
463
372
Heart
106
127
Drive
108
464
467
123
565
482
103
466
Heart
389
Heart Pl
364
94
105
9168
109
110
431
Des Arcs Road
358
Arcs
9166
113
112
104
169
Des Arcs St
Des
9138
111
Road
95
9169
9140
9174
366
96
98
573
107
468
97
155
Creek
Heart Rise
Lac
154
100
102
390
572
Des Arcs Cres
99
101
E
392
391
McGillivray Lane
Lac Des Arcs
Lac
Des
Arcs
9155
9162
Trans-Canada Highway 1
125
126
Alberta Environment
Exploration Well
Wells Not Surveyed
(location unconfirmed)
Surveyed Wells
Transect Line
163 Well Number
N
Exploration Well-8
Heart Creek
D′
490
0
500 Metres
1 km

Exshaw-Lac Des Arcs Cross Section - D to D′

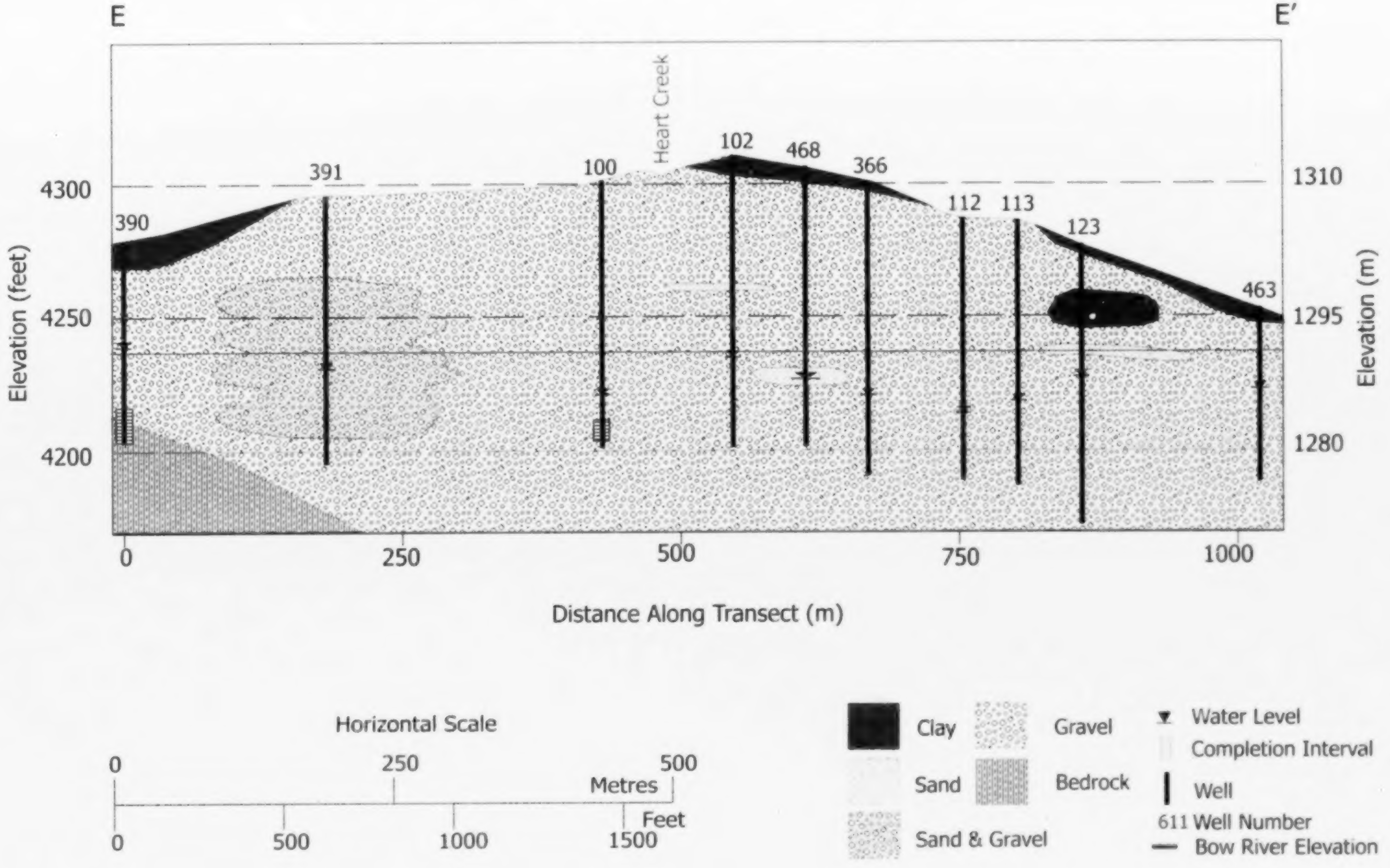

D
D′
629
163
165
166
373
436
528
439
104
97
125
126
490
Exshaw
Lac Des Arcs
Hwy 1A
Bow River
Trans Canada Hwy
? ? ? ? ? ?
4300
4200
Elevation (feet)
1310
1280
Elevation (m)
0
500
1000
1500
2000
Distance Along Transect (m)
Clay
Silt
Sand
Gravel
Bedrock
Water Level
Completion Interval
Well
611 Well Number
TH-20 Project Test Hole
Bow River Elevation
Horizontal Scale
0
500
1000
1500
Metres
0
1500
3000
4500
Feet

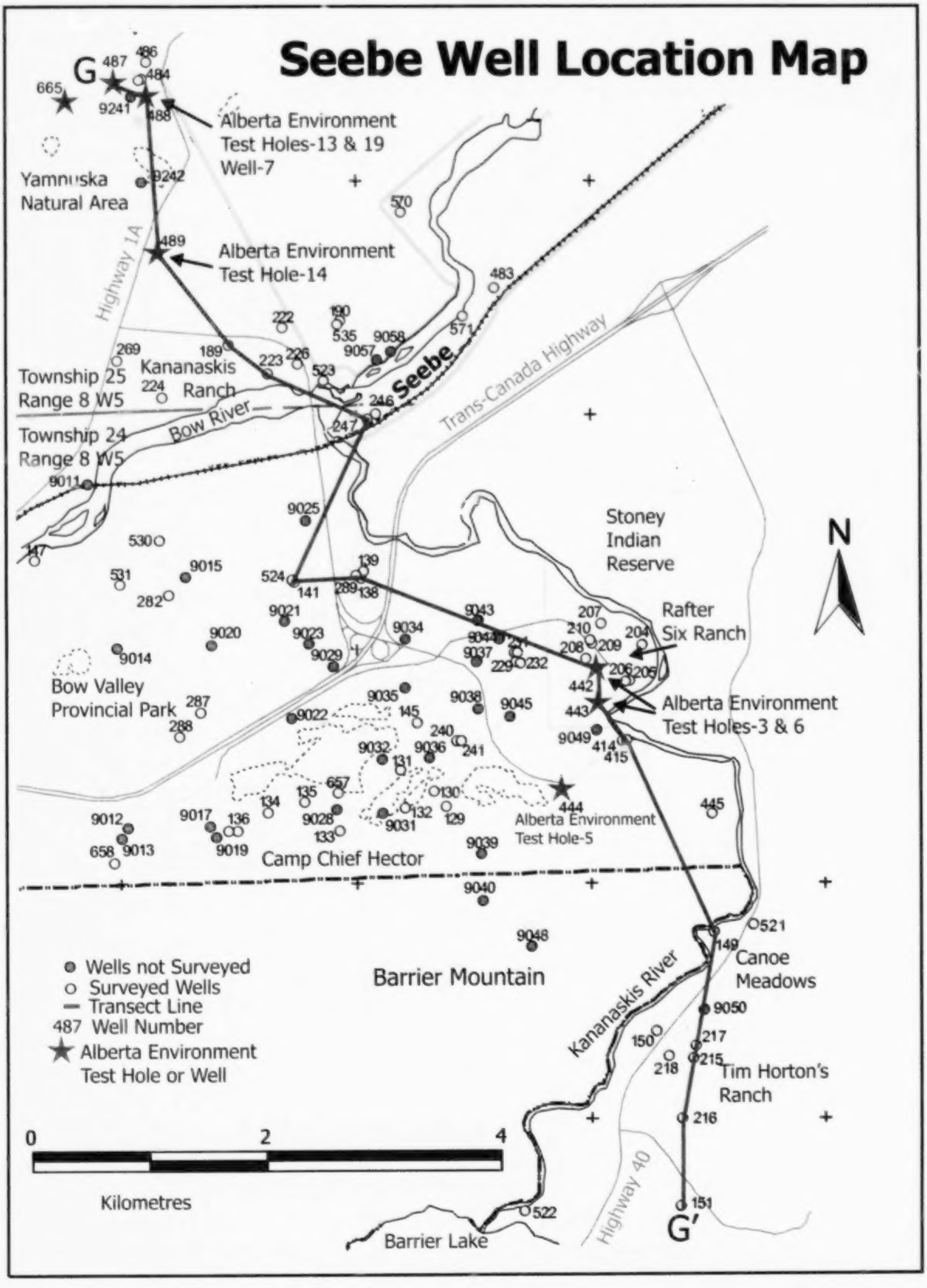


Exshaw - Lac Des Arcs Cross Section - D to E′

D
E′
Elevation (feet)
4400
4200
4000
3800
3600
Elevation (m)
1341
1280
1219
1158
1097
Exshaw
Lac Des Arcs
629
163
165
166
175
172
378
170
Hwy 1A
285
284
427
Alberta Environment Exploration Well-4 & Monitoring Well-759
Bow River
118
388
463
0
250
500
750
1000
1250
1500
1750
Distance Along Transect Line (m)
Horizontal Scale
Metres
0
250
500
750
1000
Feet
0
500
1000
1500
2000
2500
3000
Clay
Coarse Gravel
Gravel
Bedrock
Water Level
Completion Interval
Well
629 Well Number
Bow River Elevation

Lac Des Arcs Cross Section - E to E′

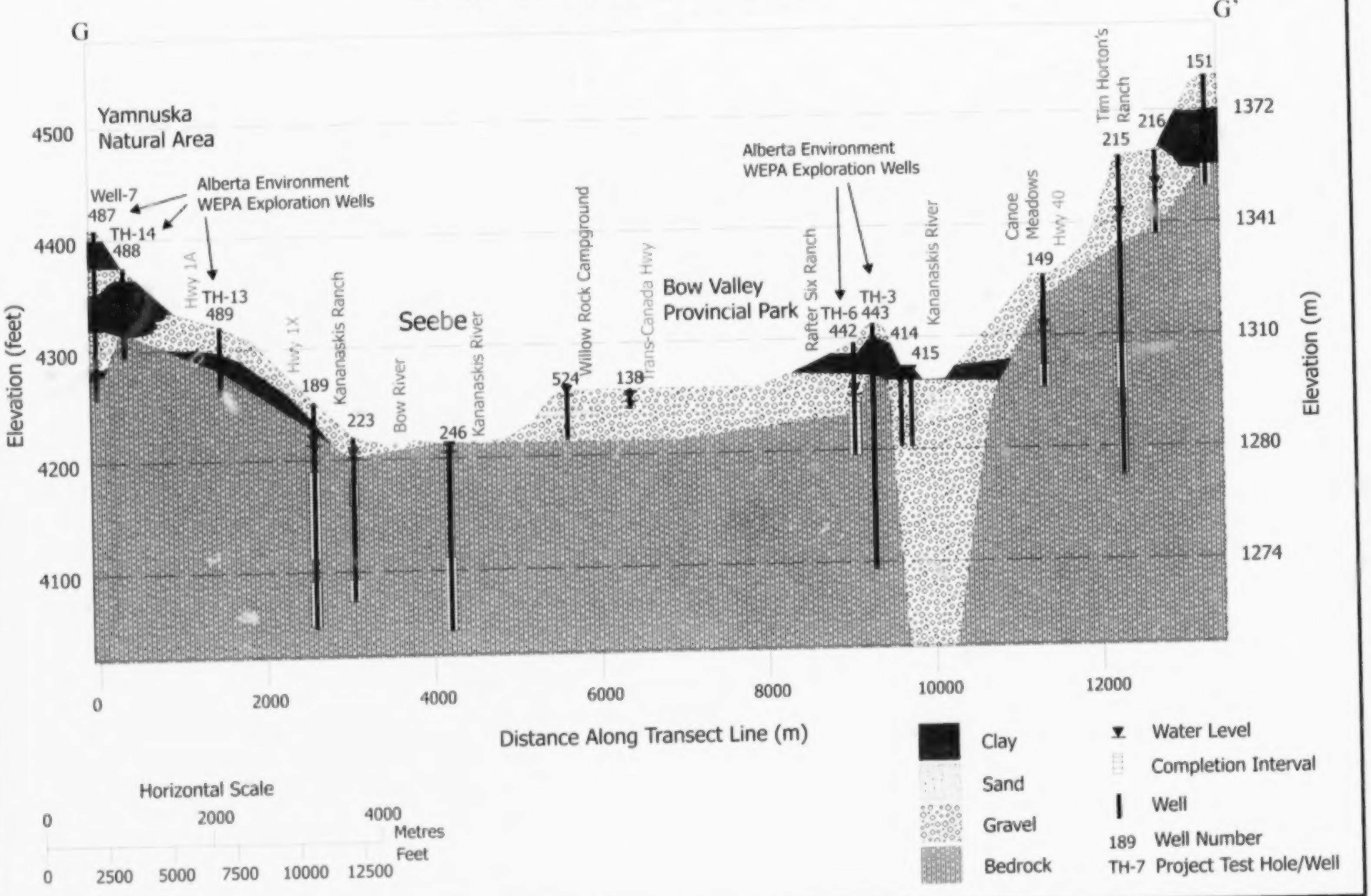

E
E′
Heart Creek
390
391
100
102
468
366
112
113
123
463
Elevation (feet)
4300
4250
4200
Elevation (m)
1310
1295
1280
0
250
500
750
1000
Distance Along Transect (m)
Horizontal Scale
0
250
500
Metres
0
500
1000
1500
Feet
Clay
Sand
Sand & Gravel
Gravel
Bedrock
Water Level
Completion Interval
Well
611 Well Number
Bow River Elevation



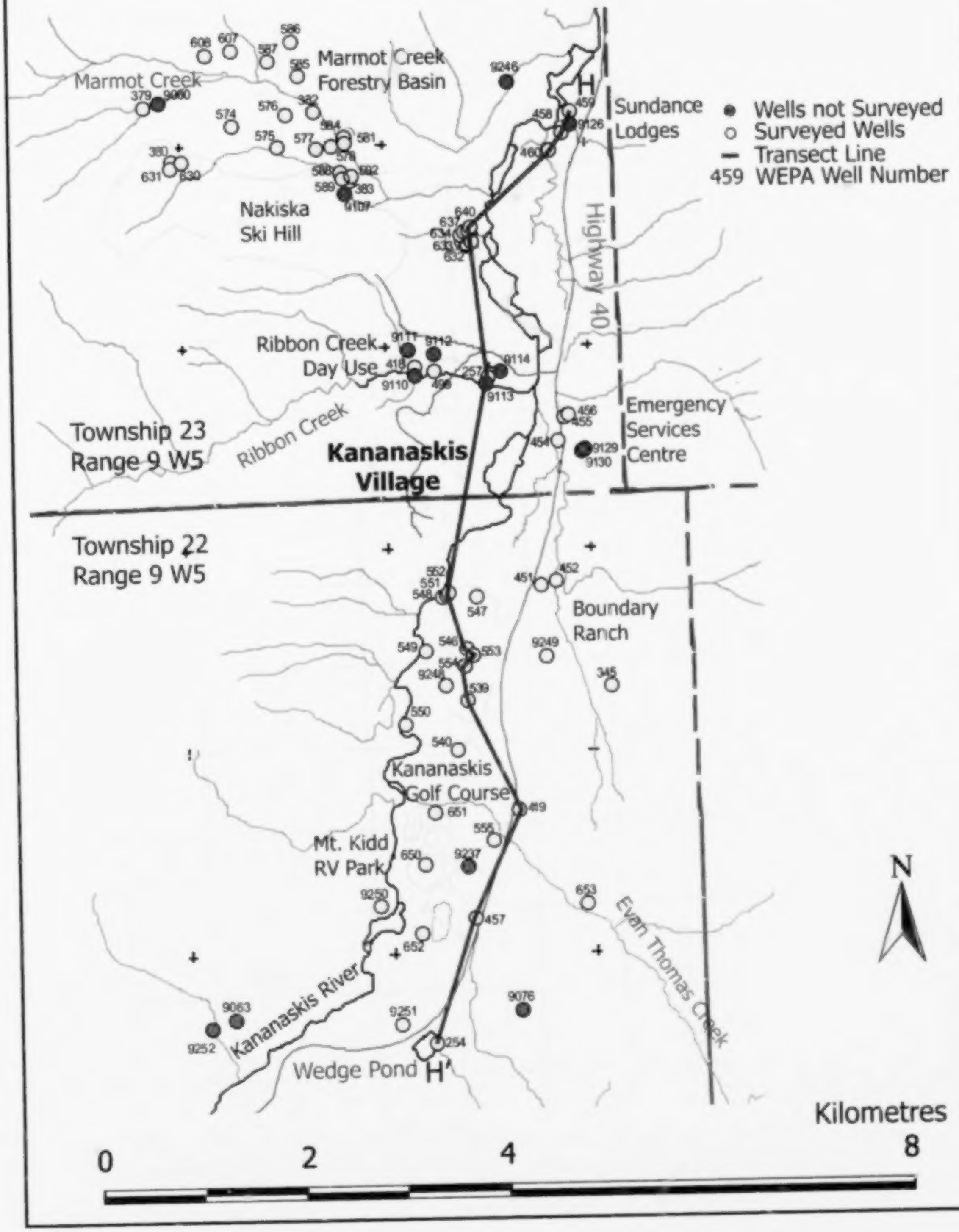
Seebe Well Location Map

G
487
486
484
665
9241
488
Alberta Environment Test Holes-13 & 19 Well-7
Yamnuska Natural Area
9242
570
Highway 1A
489
Alberta Environment Test Hole-14
483
222
190
535
9058
571
9057
189
226
223
523
269
Kananaskis Ranch
Township 25 Range 8 W5
224
Seebe
Trans-Canada Highway
246
Bow River
247
Township 24 Range 8 W5
9011
9025
Stoney Indian Reserve
N
530
147
531
9015
524
141
139
289
138
282
9021
9043
207
Rafter Six Ranch
210
204
9020
9023
9034
9044
211
208
209
9014
9029
9037
229
232
206
205
Bow Valley Provincial Park
442
287
9035
9038
9045
Alberta Environment Test Holes-3 & 6
288
9022
145
443
240
9049
241
414
415
9032
9036
131
657
130
444
135
445
134
132
129
Alberta Environment Test Hole-5
9012
9017
136
9028
9031
133
9039
658
9013
9019
Camp Chief Hector
9040
521
9048
149
Canoe Meadows
Barrier Mountain
Kananaskis River
9050
150
217
218
215
Tim Horton's Ranch
216
0
2
4
Kilometres
Highway 40
151
522
G′
Barrier Lake
● Wells not Surveyed
○ Surveyed Wells
— Transect Line
487 Well Number
★ Alberta Environment Test Hole or Well

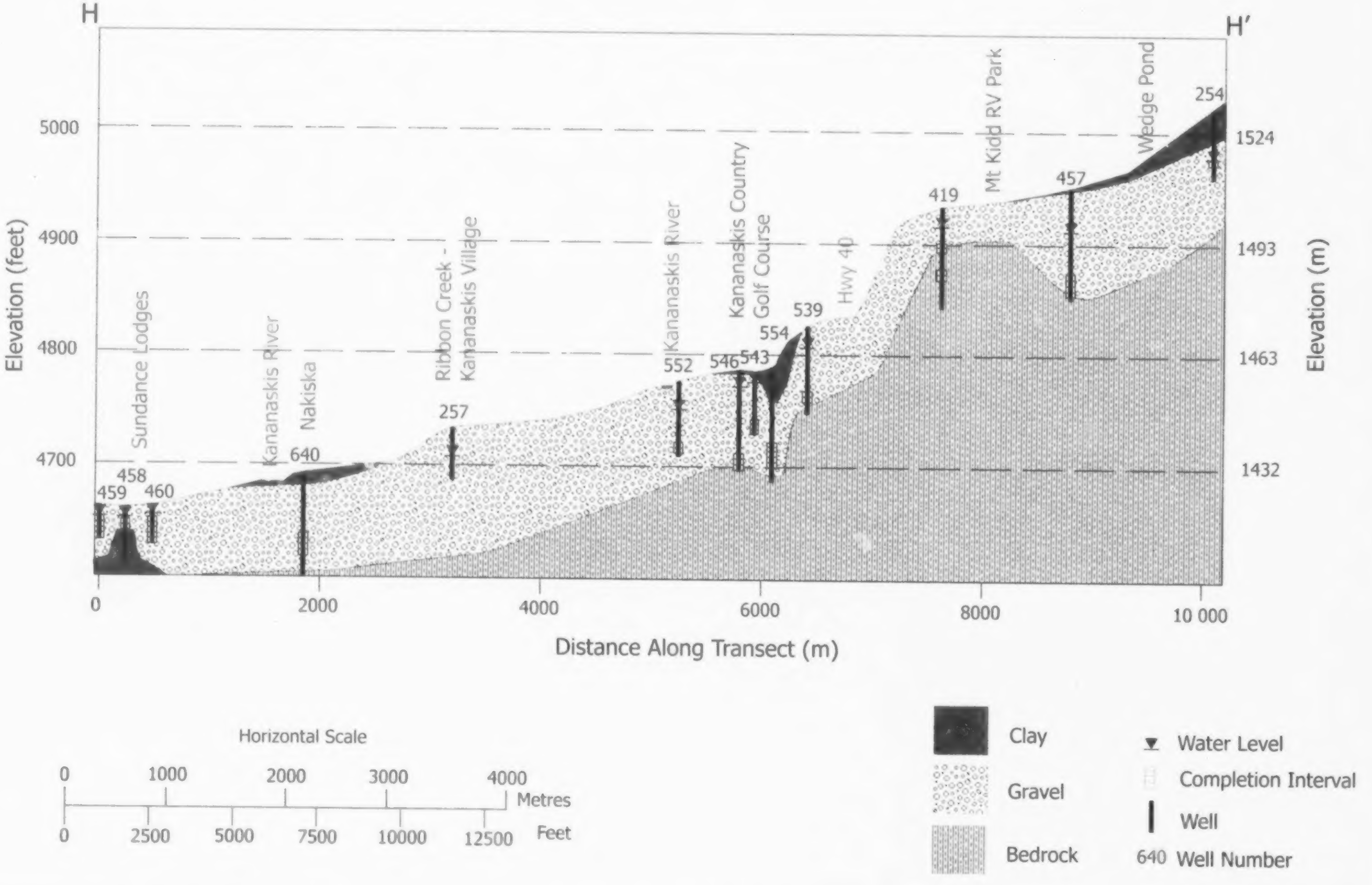
Seebe Cross Section - G to G′

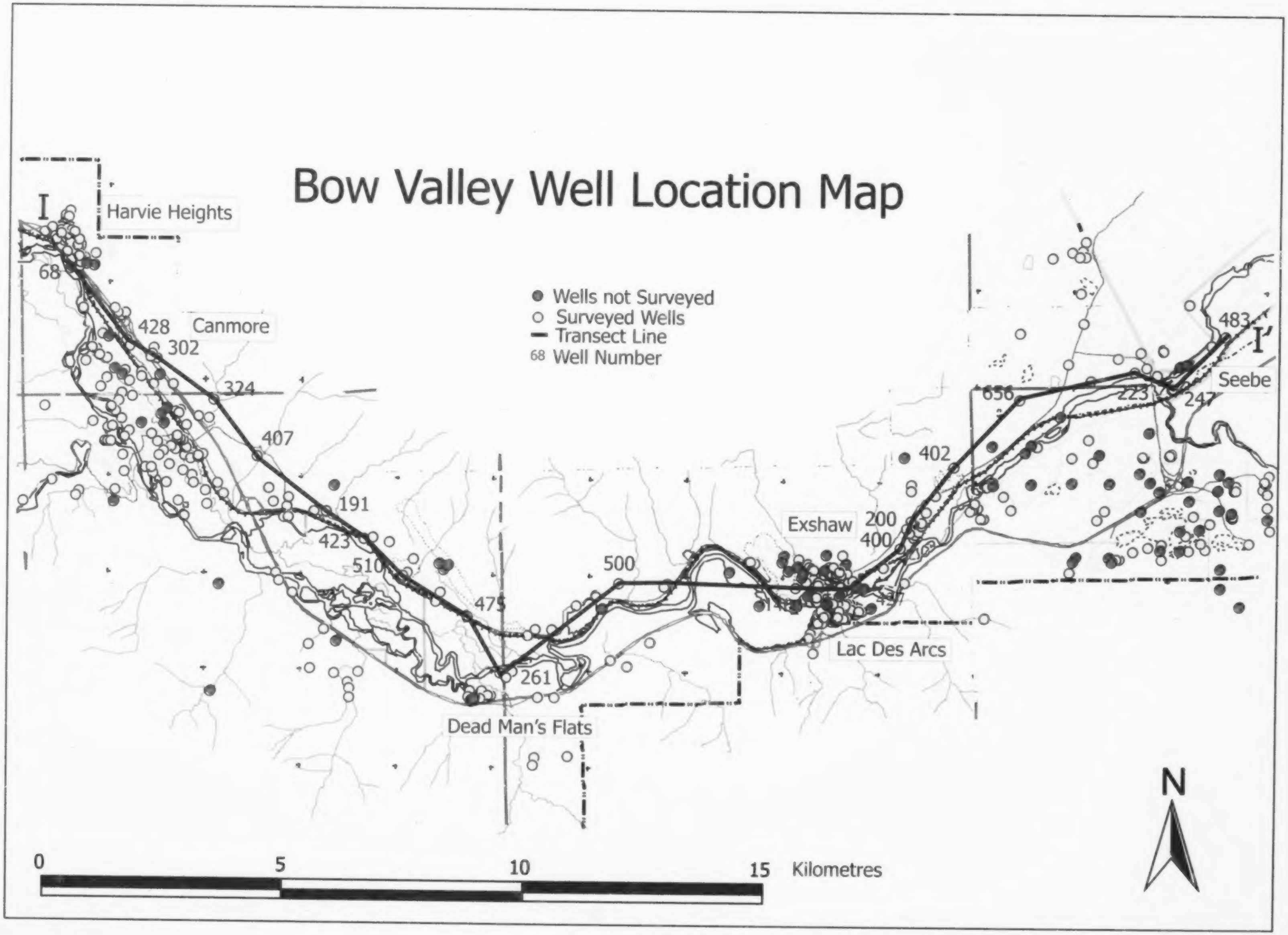

G
G'
Yamnuska
Natural Area
Well-7
487
TH-14
488
Alberta Environment
WEPA Exploration Wells
TH-13
489
Hwy 1A
Hwy 1X
189
Kananaskis Ranch
223
Bow River
Seebe
246
Kananaskis River
524
Willow Rock Campground
138
Trans-Canada Hwy
Bow Valley
Provincial Park
Rafter Six Ranch
Alberta Environment
WEPA Exploration Wells
TH-6 442
TH-3 443
414
415
Kananaskis River
Canoe
Meadows
Hwy 40
149
Tim Horton's
Ranch
215
216
151
Elevation (feet)
4500
4400
4300
4200
4100
Elevation (m)
1372
1341
1310
1280
1274
0
2000
4000
6000
8000
10000
12000
Distance Along Transect Line (m)
Horizontal Scale
0
2000
4000
Metres
0
2500
5000
7500
10000
12500
Feet
Clay
Sand
Gravel
Bedrock
Water Level
Completion Interval
Well
189 Well Number
TH-7 Project Test Hole/Well

Kananaskis Well Location Map

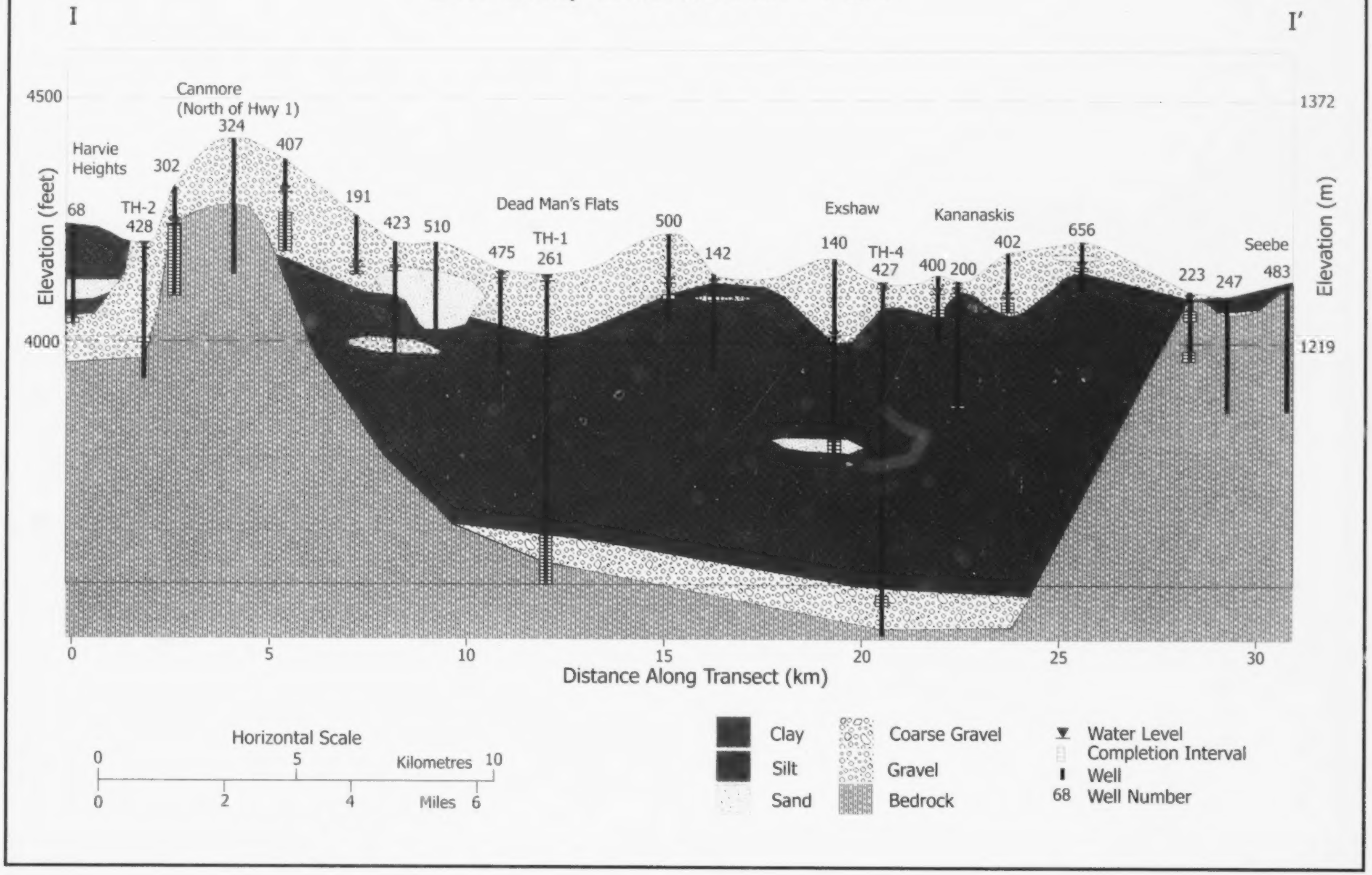

Marmot Creek
Marmot Creek Forestry Basin
Nakiska Ski Hill
Sundance Lodges
H
H'
Highway 40
Ribbon Creek Day Use
Ribbon Creek
Emergency Services Centre
Township 23 Range 9 W5
Township 22 Range 9 W5
Kananaskis Village
Boundary Ranch
Kananaskis Golf Course
Mt. Kidd RV Park
Kananaskis River
Evan Thomas Creek
Wedge Pond
● Wells not Surveyed
○ Surveyed Wells
— Transect Line
459 WEPA Well Number
N
Kilometres
0
2
4
8
608
607
586
587
585
9246
379
9060
574
576
382
584
581
575
577
578
380
631
630
588
592
589
383
9107
459
458
9126
460
640
637
634
633
632
9111
9112
418
9110
499
257
9114
9113
456
455
454
9129
9130
552
551
548
547
451
452
549
546
553
554
9248
539
9249
345
550
540
419
651
555
650
9237
653
9250
457
652
9063
9252
9251
254
9076

Kananaskis Cross Section - H to H′


H
H′
Elevation (feet)
5000
4900
4800
4700
Elevation (m)
1524
1493
1463
1432
Sundance Lodges
Kananaskis River
Nakiska
Ribbon Creek - Kananaskis Village
Kananaskis River
Kananaskis Country Golf Course
Hwy 40
Mt Kidd RV Park
Wedge Pond
459
458
460
640
257
552
546
543
554
539
419
457
254
0
2000
4000
6000
8000
10 000
Distance Along Transect (m)
Horizontal Scale
0
1000
2000
3000
4000
Metres
0
2500
5000
7500
10000
12500
Feet
Clay
Gravel
Bedrock
Water Level
Completion Interval
Well
640 Well Number


Bow Valley Well Location Map
● Wells not Surveyed
○ Surveyed Wells
— Transect Line
68 Well Number
I
Harvie Heights
68
428
Canmore
302
324
407
191
423
510
475
261
Dead Man's Flats
500
Exshaw
200
400
Lac Des Arcs
402
656
223
247
Seebe
483
I'
N
0
5
10
15
Kilometres

Bow Valley Cross Section - I to I′


I
I′
Elevation (feet)
4500
4000
Elevation (m)
1372
1219
Harvie Heights
68
TH-2
428
302
Canmore (North of Hwy 1)
324
407
191
423
510
Dead Man's Flats
475
TH-1
261
500
142
Exshaw
140
TH-4
427
Kananaskis
400
200
402
656
223
247
Seebe
483
0
5
10
15
20
25
30
Distance Along Transect (km)
Horizontal Scale
0
5
Kilometres 10
0
2
4
Miles 6
Clay
Silt
Sand
Coarse Gravel
Gravel
Bedrock
Water Level
Completion Interval
Well
68 Well Number

Appendix D

Hydrogeology of Communities

- Canmore
- Harvie Heights
- Dead Man's Flats
- Lac des Arcs
- Exshaw
- Evan Thomas / Kananaskis Valley

Canmore

The Community

Canmore was established in 1884 as a divisional point on the CPR mainline and soon became important as a mining and service centre. The community was built on the floodplain of the Bow River where groundwater supplies were readily available. Canmore residents obtained their water from domestic wells until 1965 when, at a population of 2000, the Town was incorporated and a water utility was built. The Town supply is obtained from wells near the Rundle Plant, by the Bow River and from backup wells adjacent to Policeman's Creek near Railway Avenue and Bow Valley Trail, none of which exceed 25 m in depth. This is augmented by surface water obtained from the TransAlta Utilities Rundle Forebay reservoir.

In recent years, Canmore has expanded beyond the Bow River floodplain, east into the Cougar Creek district, south into the Three Sisters area on the north-facing benchlands and north into Silver Tip on the south-facing benchlands. These subdivisions are connected to the existing water supply. Few wells existed in these areas prior to development, and new wells were generally not required, so minimal groundwater information is available.

Aquifers

Central Canmore and the older subdivisions are low-lying relative to the Bow River, and the water table is typically in the range of 2 to 5 m below surface (Table A). Policeman's Creek and Spring Creek are fed from the water table and do not freeze over in the winter. They provide important trout spawning and waterfowl habitat. The water table fluctuates seasonally and is monitored by the Town of Canmore from a series of shallow observation wells. Most of the wells in the floodplain are relatively shallow, less than 20 m deep. High yields are obtainable at shallow depths. Before the central supply was built, the typical domestic well was a sand point driven into the coarse gravel, sand and silt aquifer.

The ready availability of significant supplies of groundwater at a relatively shallow depth, and the difficulty of drilling deeper wells through the saturated gravels, meant that the vertical extent of the aquifer near Canmore remained unknown. We drilled exploratory wells at the Alberta tourism centre near the highway interchange and on Alberta public lands south of the Heliport. The well at the tourist centre was drilled to a depth of 85 m. It encountered gravel from surface to 68 m, followed by four metres of gravel and clay overlying black shale. It was tested at a rate of 525 m^3/day and had a non-pumping water level of three metres. The well was incorporated into Alberta Environment's groundwater monitoring well network in 2001. The well near the heliport was drilled to a depth of 192 m. It did not penetrate bedrock, anticipated at around 220 m depth. The well encountered gravel and sand to a depth of 110 m, followed by clay to 133 m and sand and gravel to 192 m, terminating in very coarse gravel. It was not tested, but yields are expected to exceed 2000 m^3/day. The non-pumping water level is 3 m below ground level. The two exploratory wells confirmed the presence of the Calgary Buried Valley Aquifer beneath central Canmore. The buried valley has considerable production potential.

The Cougar Creek area is underlain by alluvial fan deposits, consisting of gravel and minor sand, silt and clay rising above the level of the floodplain. The alluvial fan deposits and underlying river alluvium form an unconfined aquifer. The depth to water varies with the land elevation, but is generally within the range of 15 to 20 m. Reported yields vary from 65 to 165 m^3/day. Sufficient yields for domestic purposes were found at depths above the base of the aquifer, and none penetrated to bedrock. Yields might be significantly improved by drilling deeper into the aquifer.

The Three Sisters area south of the Bow River is underlain by clay, sand and gravel, often less than 20 m thick, draped over sandstone, shale and coal bedrock. Generally, yields appear to be poor, and water quality may be compromised where coal is encountered. Reasonable yields are possible. A well drilled at the Stewart Creek Golf Course in the Three Sisters development drilled past the low-yielding drift into bedrock, obtaining a yield of 65 m^3/day from shattered sandstone.

There is a lack of drilling information for the Silver Tip area, but the relatively thin interval of drift encountered suggests that the area is a poor prospect. A well drilled for the Silver Tip golf course was unsuccessful in obtaining water. The ground elevation was 60 m above the floodplain, but the drift thickness was only 40 m and the remaining 45 m interval in bedrock was also "dry".

In Harvie Heights, also located on the benchlands, the drift is considerably thicker, exceeding 90 m in most cases. Groundwater is obtained from an upper aquifer, perched on a layer of clay till, and a lower aquifer with a water level close to that of the Bow River.

Groundwater Chemistry

The proportions of major constituents of groundwater in the Canmore area (Table B) are similar to those of the Bow River, but the concentrations are higher. The water is calcium-magnesium-bicarbonate-sulphate type. When examining all samples from Canmore and vicinity, the total dissolved solids concentration averages 245 mg/L with a standard deviation of 159; however, the average is influenced by mineral springs in the Three Sisters area. Once the anomalous samples are removed, the total dissolved solids concentrations average 200 mg/L with a standard deviation of 38.

Table A - Aquifer and yield characteristics - Canmore / Subdivisions

Aquifer	Yield m^3/day m	Water Level Elevation m	Water Level below surface m	Base of Aquifer below surface
Central Canmore	>150	1310	3	220 (estimated)
Cougar Creek	165	1310	15 to 20	220
Three Sisters	low	NA	NA	Variable
Silver Tip	low	NA	NA	Variable

Table B - Average concentrations of major constituents in Groundwater - Canmore, and Bow River water expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ)
*maximum allowable concentration

Source	TDS	Hard	Ca	Mg	Na	HCO_3	SO_4	Cl	Fe	NO_3	F	n
Guidelines- CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Bow River	172	165	43	14	2	145	42	2	0.1	0.08		2
Canmore & Vicinity	245	84	54	18	14	197	56	2	1.2	0.11	0.18	68
Canmore	200	52	46	15	3	157	38	2	1.3	0.13	0.15	57
Floodplain	203	55	47	15	2	160	38	2	1.4	0.13	0.16	49
Cougar Creek	183	34	44	14	4	123	39	2	-	-	0.12	8

All parameters meet the *Guidelines For Canadian Drinking Water Quality* with the exception of iron. The average concentration of iron exceeds the aesthetic objective (AO), but is likely more indicative of well, rather than aquifer conditions.

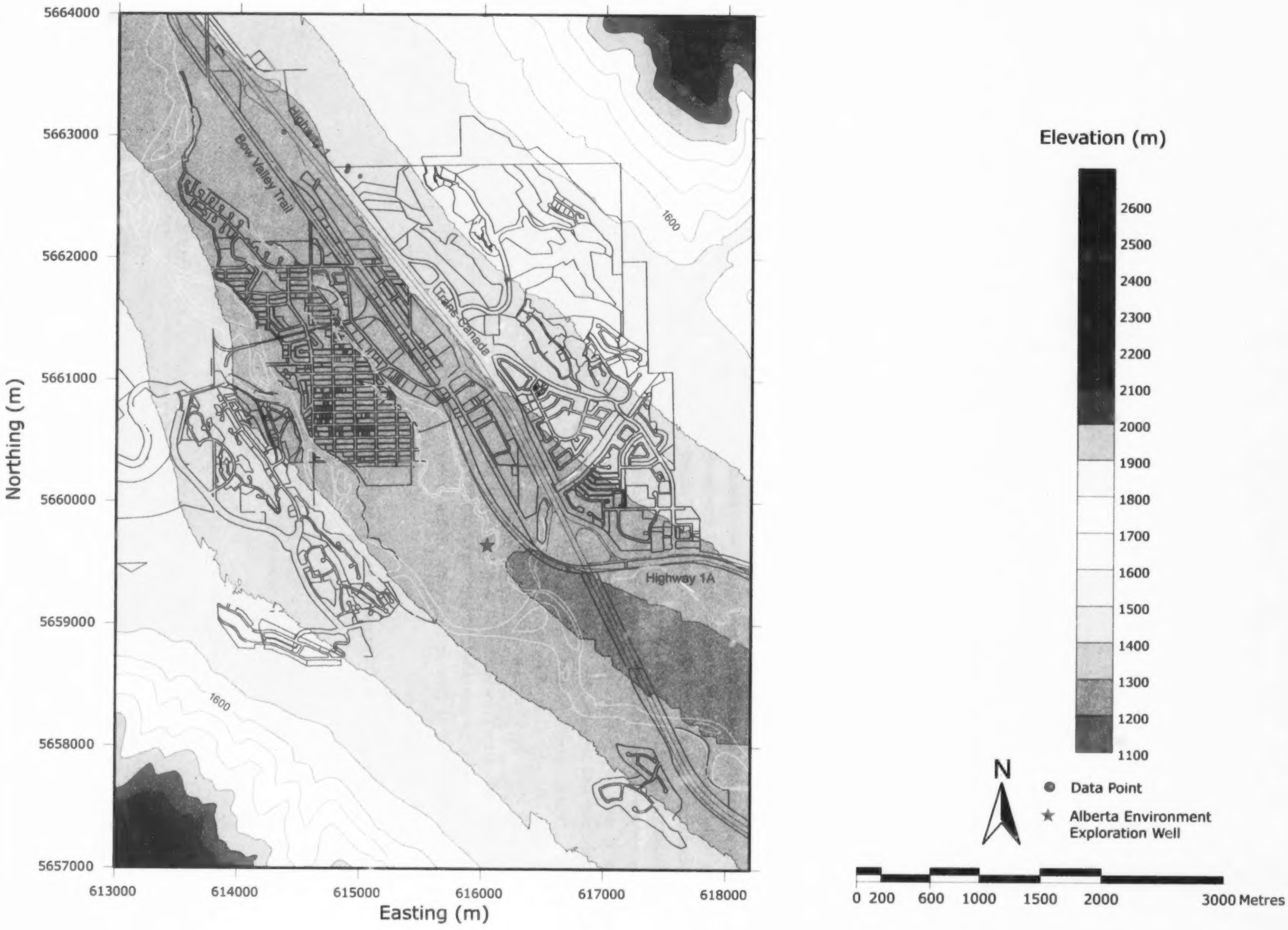
Groundwater Numerical Model

We created a groundwater model using Visual MODFLOW that simulates flow conditions for the Canmore area, included with this report, on CD. The model covers the Bow Valley from the Banff Park boundary almost to Dead Man's Flats. It is 14,200 m long and 7,750 m wide (approximately 220 km^2) with its origin at UTM coordinate 60710000 E and 56520546 N. The model is rotated from the north-south positions by -39.289 degrees to parallel the Bow Valley, while retaining a modified UTM coordinate system.

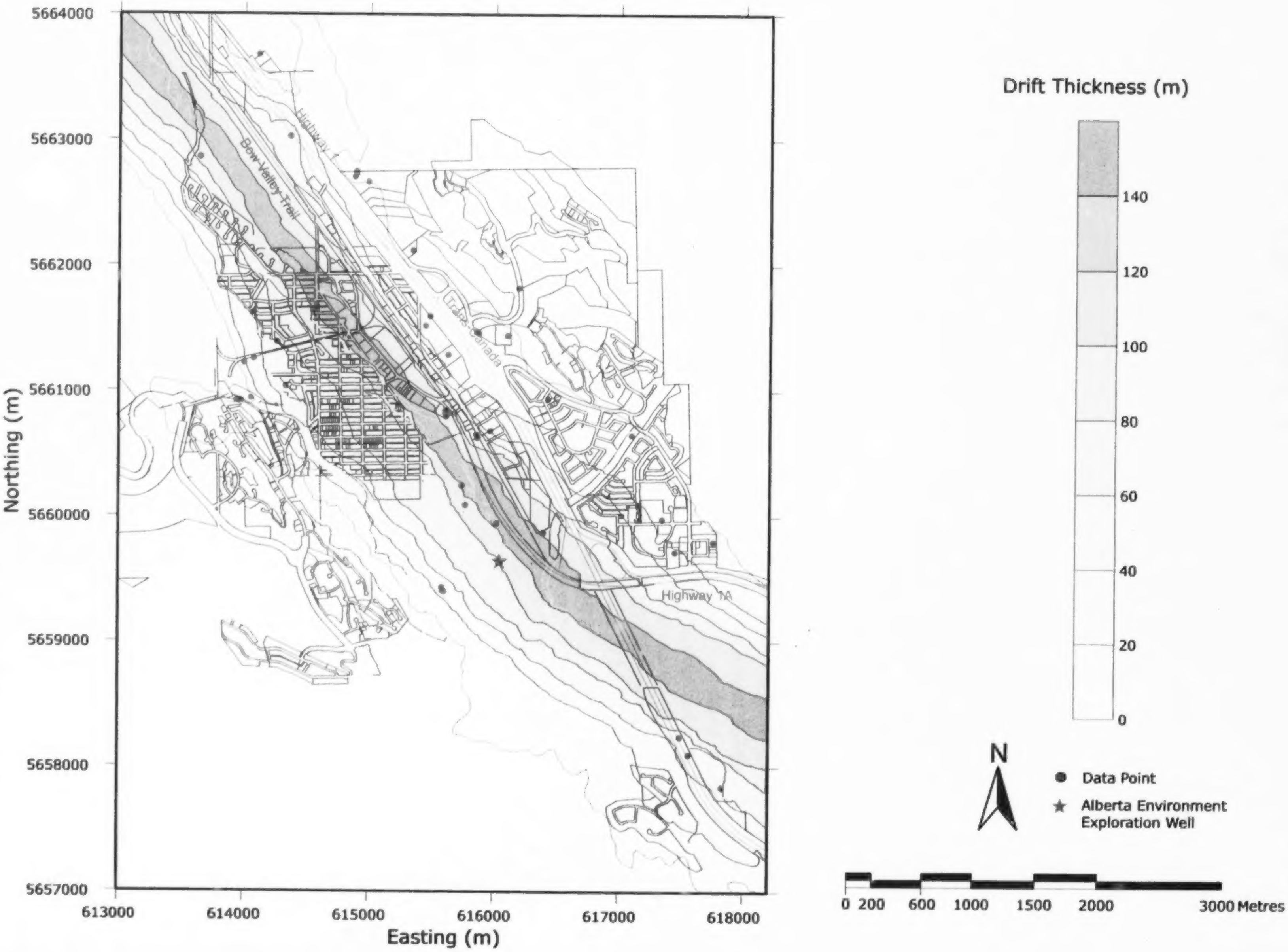
The model is based on a geological understanding of currently available well data and aquifer conditions. Its upper boundary is the land surface, and the lower boundary, the bedrock contact. It consists of three layers: an upper high permeability aquifer, a middle low permeability aquitard and a high permeability lower aquifer. It simulates baseline groundwater conditions and may be modified to predict the effects of pumping on the groundwater system including water levels and flow directions or to predict the migration of a contaminant spill. The model shows that groundwater flows toward the centre of the valley from the mountainsides and eastward. The vertical component of flow in the centre of the valley is upward.

For more information on Canmore, see Appendices B, C, D and F.

Bedrock Topography - Canmore


5664000
5663000
5662000
5661000
5660000
5659000
5658000
5657000
Northing (m)
613000
614000
615000
616000
617000
618000
Easting (m)
Bow Valley Trail
Highway 1
Trans-Canada
Highway 1A
1600
1600
Elevation (m)
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
N
Data Point
Alberta Environment Exploration Well
0 200 600 1000 1500 2000 3000 Metres

Drift Thickness - Canmore


Northing (m)
5664000
5663000
5662000
5661000
5660000
5659000
5658000
5657000
Easting (m)
613000
614000
615000
616000
617000
618000
Highway 1
Bow Valley Trail
Trans-Canada
Highway 1A
Drift Thickness (m)
140
120
100
80
60
40
20
0
N
● Data Point
★ Alberta Environment Exploration Well
0 200 600 1000 1500 2000 3000 Metres

Harvie Heights

The Community

Harvie Heights is located on south-facing benchlands northwest of Canmore. The hamlet, established in the 1950s, occupies three terraces. The lowest terrace, slightly above the level of the Bow River, hosts the commercial strip facing Harvie Heights Road and a few houses on Blue Jay Drive. The second terrace is located above a small escarpment used as a utility corridor; it includes Bow River Drive and Elk Street. Spray Drive, Rundle Road and Cascade Drive are located on the third terrace. Harvie Heights is served entirely by private wells. The hamlet has the highest density of wells in the Canmore-Kananaskis region. Over 130 are located in an area smaller than a quarter section.

Aquifers

The geology beneath Harvie Heights consists of gravel, sand silt and clay from glacial outwash deposits, overlain in the west by alluvial fan deposits. Mostly, the substrate is an indistinct mixture of gravel in a matrix of sand, silt and clay in varying proportions depending on location and depth. Where fine matrix materials predominate, they form an aquitard. Where the matrix is mainly sand and gravel, it forms an aquifer. Despite a significant variation in reported lithologies on drilling reports, two regional aquifers were recognized.

The lower aquifer is accessible by residents of the two lower terraces along Bow River Drive and Harvie Heights Road. Its water elevation is comparable to that of the Bow River at around 1320 m. The aquifer is overlain by an aquitard corresponding approximately to the level of the first terrace. Residents of the remainder of Harvie Heights access an upper aquifer perched on the clay layer with a groundwater elevation of about 1350 m. It averages 40 m thick, while the lower aquifer exceeds 60 m. The upper and lower aquifers appear to be in communication where the aquitard is thin or absent. This causes a lowering of the water level in the upper aquifer.

A low-lying drainage area dissects the central part of Harvie Heights. Groundwater discharges from the upper aquifer along the first escarpment and in reserve land P18, below Bow River Drive. The discharge is mostly seepage, apart from a spring located behind the Gateway Motel, on Block 24, Lot 3, Plan 6402 HX. Opposite the top of the reserve, Block 2, Lot 7, Plan 6402 HX on Bow River Drive has a "flowing" well.

Table C – Aquifer Characteristics and Yield – Harvie Heights

Aquifer	Yield m^3/day m	Water Level Elevation m	Water Level below surface m	Base of Aquifer below surface
Upper Aquifer	30 to 160	1350	15	40
Lower Aquifer	160 to 650	1320	10	>60

We drilled an exploratory and monitoring well in Harvie Heights in Block 2, Lot P-6, Plan 6402 HX between Cascade Drive and Spray Drive. The well confirmed the upper aquifer between a depth of 35 m and 58 m (1319 to 1342 m elevation), overlying bedrock. The water level was at a depth of 32 m (1345 m elevation) and the yield was estimated at 160 m^3/day. Monitoring of water levels began in early 2002. Yields in the upper hamlet are in the range of 30 to 160 m^3/day (5 to 25 igpm); yields in the lower hamlet fall in the range of 160 to 650 m^3/day (25 to 100 igpm). (Table C).

Groundwater Chemistry

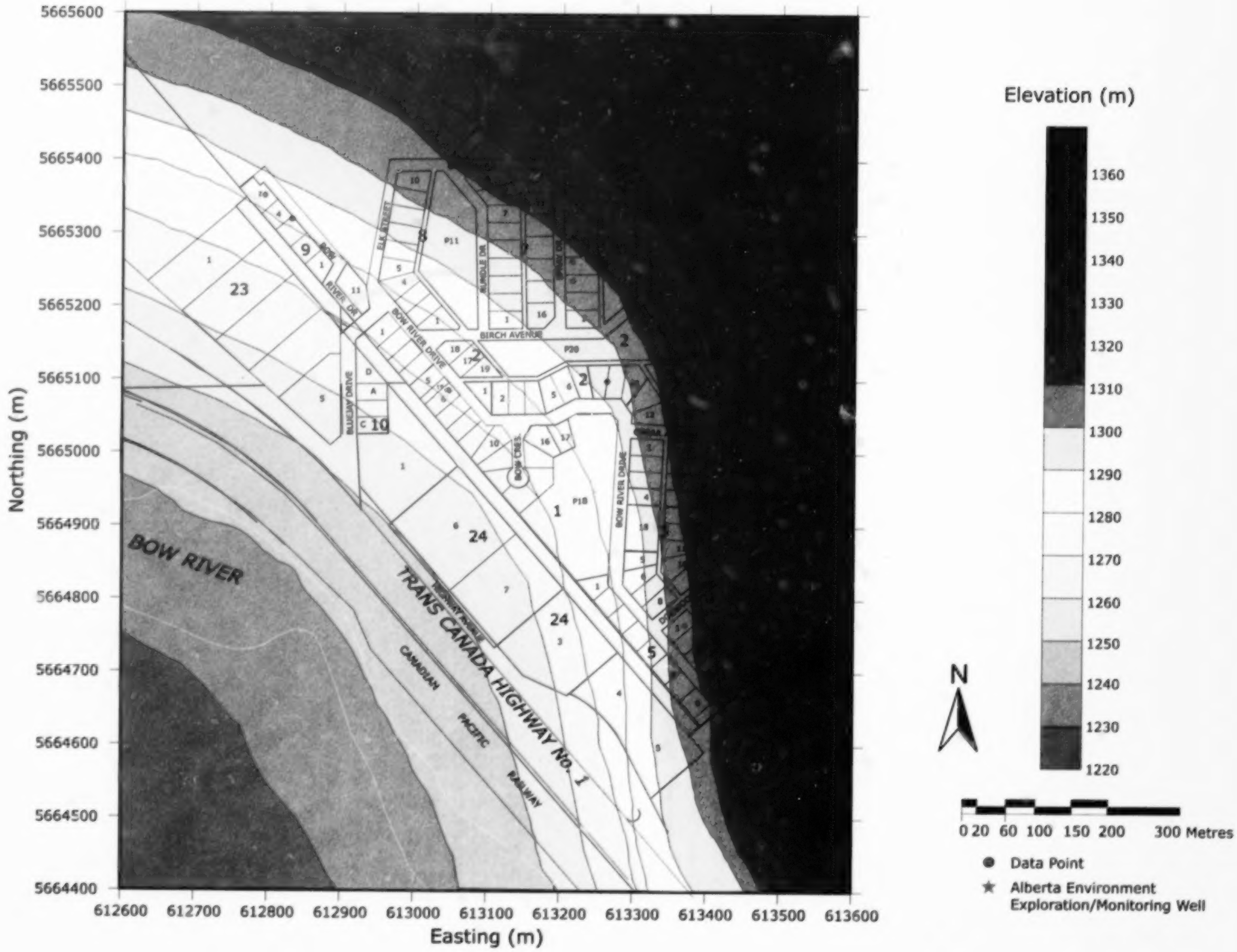
In both the upper and lower aquifers, the water type is calcium-magnesium-bicarbonate and parameters are similar (Table D). The south-facing benchlands are elevated, consisting of relatively coarse materials probably derived from low-sulphate carbonate rock of the Rundle Group. All parameters meet the *Guidelines For Canadian Drinking Water Quality* with the exception of iron in the upper aquifer. The average concentration of iron exceeds the aesthetic objective, but is likely more indicative of well, rather than aquifer conditions.

For more information on Harvie Heights see Appendices B, C and E.

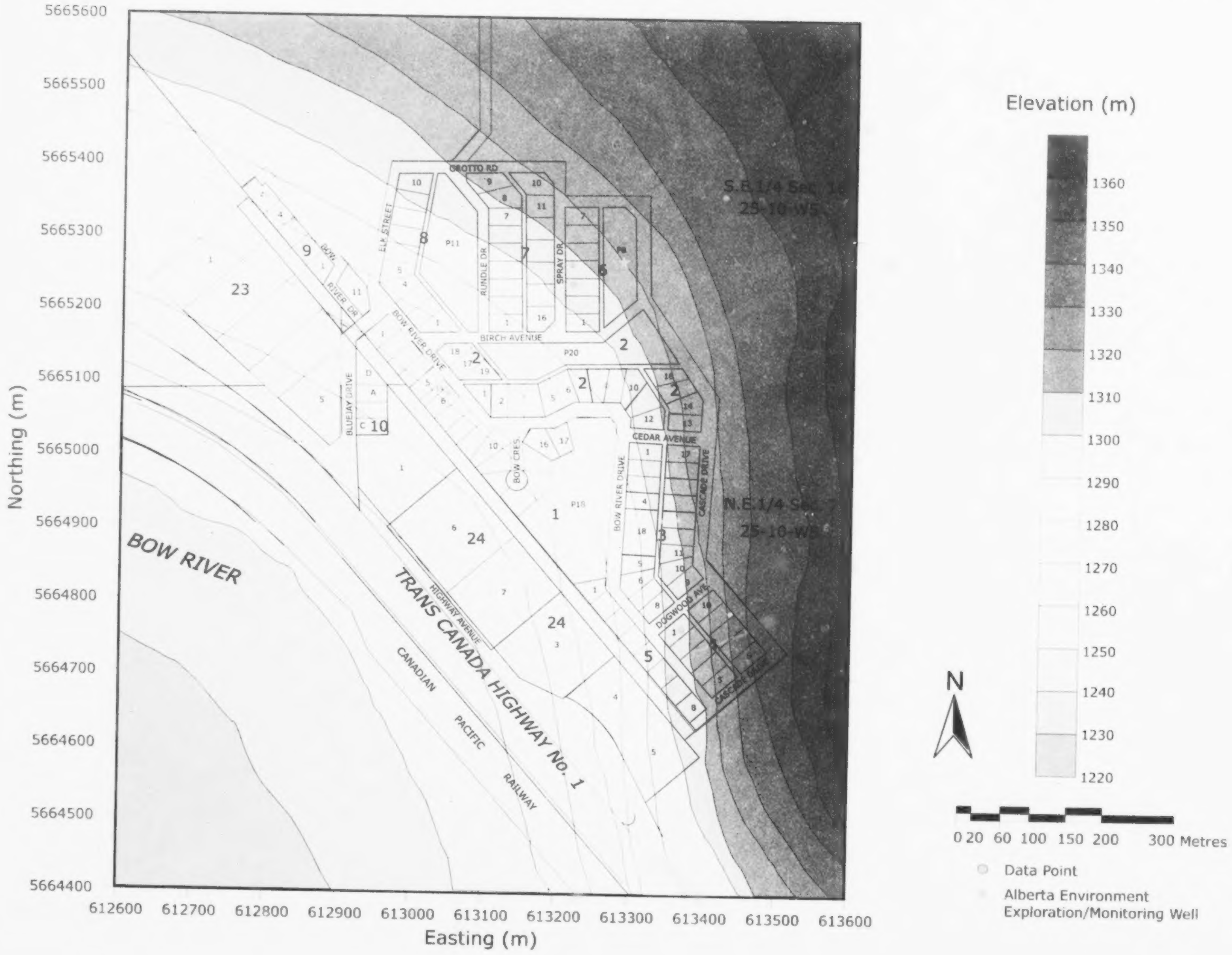
Table D - Average concentrations of major constituents in Groundwater - Harvie Heights, Upper and lower aquifers and Bow River water expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ)
*maximum allowable concentration

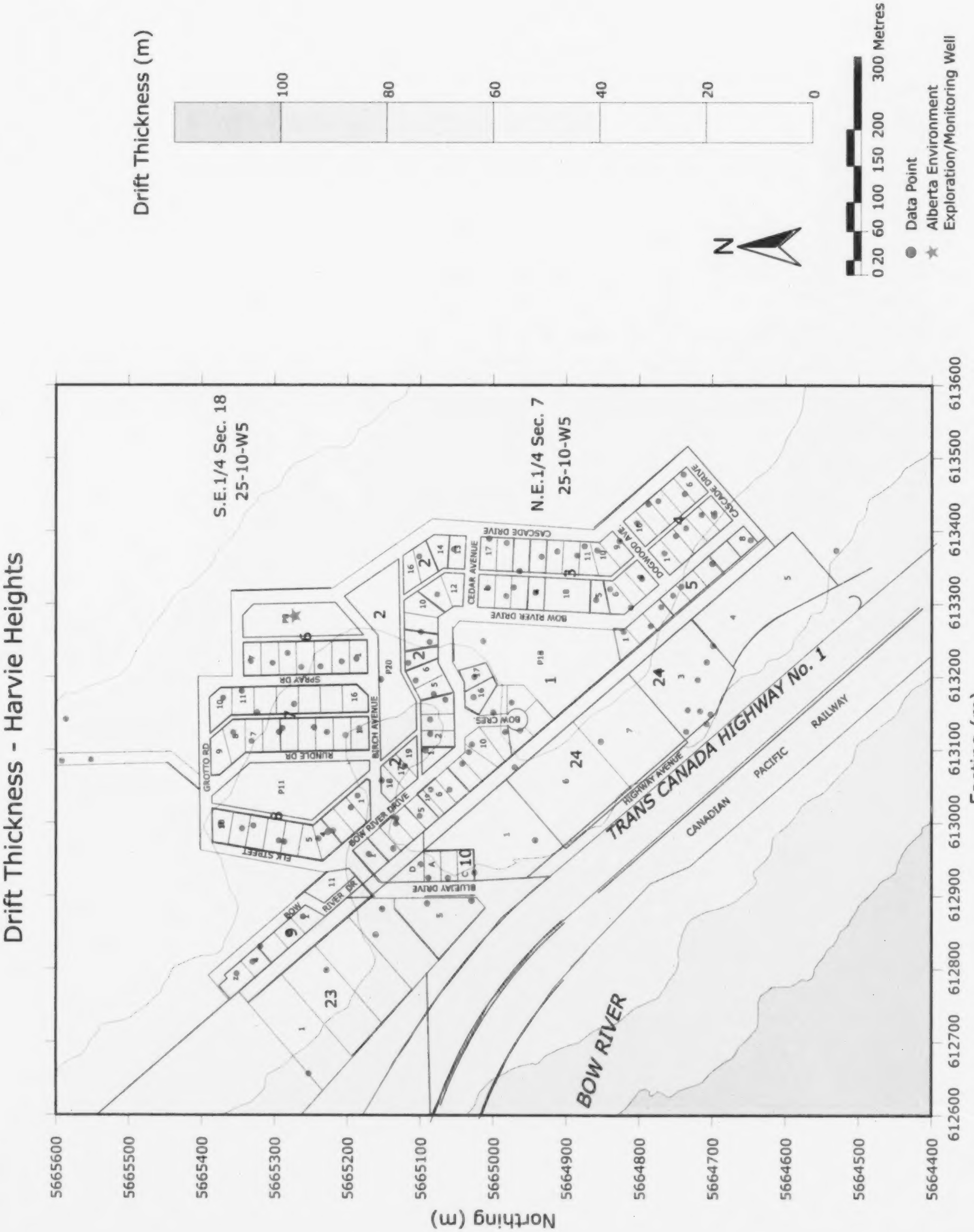
Source	**TDS**	**Hard**	**Ca**	**Mg**	**Na**	**HCO_3**	**SO_4**	**Cl**	**Fe**	**NO_3**	**F**	**n**
Guidelines-CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Bow River	172	165	43	14	2	145	42	2	0.1	0.08		2
Upper	256	130	62	22	10	243	24	17	0.95	0.73	0.19	34
Lower	240	184	56	27	7	250	22	6	0.13	0.98	0.19	11
MonitoringWell (upper)	231	230	53	24	3	239	33	0.5	0.25	0.12	0.25	1

Bedrock Topography - Harvie Heights


Northing (m)
5665600
5665500
5665400
5665300
5665200
5665100
5665000
5664900
5664800
5664700
5664600
5664500
5664400
Easting (m)
612600
612700
612800
612900
613000
613100
613200
613300
613400
613500
613600
BOW RIVER
TRANS CANADA HIGHWAY No. 1
CANADIAN PACIFIC RAILWAY
BOW RIVER DRIVE
BIRCH AVENUE
BLUEJAY DRIVE
ELK STREET
RUNDLE DR.
BOW CRES.
BOW RIVER DR.
Elevation (m)
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
1230
1220
N
0 20 60 100 150 200 300 Metres
Data Point
Alberta Environment Exploration/Monitoring Well

Bedrock Topography - Harvie Heights


Northing (m)
5665600
5665500
5665400
5665300
5665200
5665100
5665000
5664900
5664800
5664700
5664600
5664500
5664400
Easting (m)
612600
612700
612800
612900
613000
613100
613200
613300
613400
613500
613600
BOW RIVER
TRANS CANADA HIGHWAY No. 1
HIGHWAY AVENUE
CANADIAN
PACIFIC
RAILWAY
GROTTO RD
ELK STREET
RUNDLE DR
SPRAY DR
BIRCH AVENUE
BOW RIVER DRIVE
BOW RIVER DR
BLUEJAY DRIVE
BOW CRES
CEDAR AVENUE
CASCADE DRIVE
DOGWOOD AVE
P11
P20
P18
S.E.1/4 Sec. 16
25-10-W5
N.E.1/4 Sec. 9
25-10-W5
Elevation (m)
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
1230
1220
N
0 20 60 100 150 200 300 Metres
Data Point
Alberta Environment
Exploration/Monitoring Well



Drift Thickness - Harvie Heights

Northing (m)
Easting (m)
5665600
5665500
5665400
5665300
5665200
5665100
5665000
5664900
5664800
5664700
5664600
5664500
5664400
612600
612700
612800
612900
613000
613100
613200
613300
613400
613500
613600
S.E.1/4 Sec. 18
25-10-W5
N.E.1/4 Sec. 7
25-10-W5
TRANS CANADA HIGHWAY No. 1
CANADIAN PACIFIC RAILWAY
BOW RIVER
HIGHWAY AVENUE
BOW RIVER DRIVE
BOW RIVER DR
BLUEJAY DRIVE
ELK STREET
RUNDLE DR
SPRAY DR
GROTTO RD
BIRCH AVENUE
CEDAR AVENUE
CASCADE DRIVE
DOGWOOD AVE
BOW CRES.
P11
P18
P20
Drift Thickness (m)
100
80
60
40
20
0
N
0 20 60 100 150 200 300 Metres
Data Point
Alberta Environment Exploration/Monitoring Well

Dead Man's Flats

The Community

Dead Man's Flats was developed east of Canmore in the late 1950s primarily as a service centre, providing gas and lodging along the newly built Trans-Canada Highway. It has a relatively small residential population and only 14 recorded water wells.

Aquifers

Dead Man's Flats is built on the alluvial fan of Pigeon Creek, which drains the Wind Valley region. The alluvial fan encroaches upon the floodplain of the Bow River, combining with fluvial deposits to form an unconfined aquifer. The aquifer has a water table at an elevation of around 1292 m, comparable to the level of the Bow River, or 2 to 12 m below surface. Most wells in the area do not penetrate the base of the aquifer, as sufficient yields (160 to 650 m^3/ day) for commercial and domestic purposes are available at relatively shallow depths of 10 to 25 m (Table 5).

We drilled a deep exploratory hole at Dead Man's Flats, east of the developed area. Drilling revealed an alluvial sand and gravel aquifer extended to a depth of 34 m, followed by 131 m of clay till. Below the clay till, 15 m of sand and gravel, formed a second aquifer resting on limestone bedrock. The lower gravel represents the edge of the Calgary Buried Valley aquifer. Yields at this site were poor, probably related to well completion. Our exploratory well in the same aquifer at Exshaw, encountered a thicker interval yielding in excess of 2000 m^3/day. The extent of the buried valley aquifer below the remainder of Dead Man's Flats is not known. The hole, completed as a two-inch piezometer in the deep aquifer, was added to Alberta Environment's groundwater monitoring well network in 2000. (Table E).

Groundwater Chemistry

Few groundwater chemical analyses are available for Dead Man's Flats. There are 13 analyses from a variety of sources in the region. These include several samples from springs sourced from bedrock and the Alpine Resort Haven, but only four samples are from wells in the main hamlet. Groundwater composition is variable (Table F). Water from the upper gravel aquifer in the hamlet appears to be calcium-magnesium-bicarbonate-sulphate type. Higher than background concentrations of sodium, chloride and

Table E – Aquifer Characteristics and Yield – Dead Man's Flats

Aquifer	**Yield m^3/day m**	**Water Level Elevation m**	**Water Level below surface m**	**Base of Aquifer below surface m**
Alluvial	160 to 650	1292	6	34 - 40
Buried Valley	Probably >650 (Uncertain)	1292	6	>180

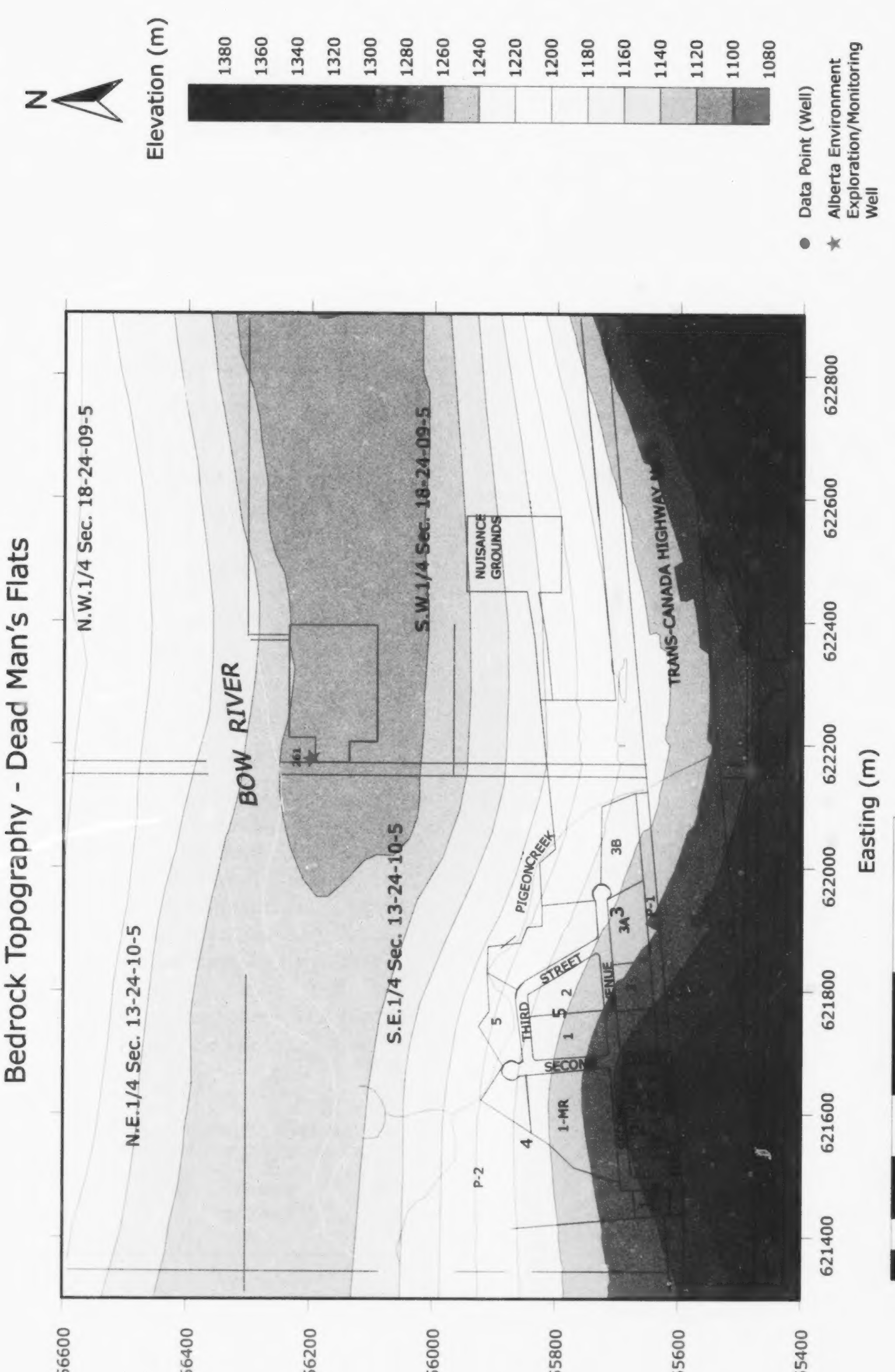
nitrate at some sites suggest that groundwater quality at some locations may have been affected by external influences.

Pigeon Creek drains Wind Valley, which is underlain by bedrock primarily of the Kootenay Group, but also the Fernie Group and Sulphur Mountain Formation. As the alluvial fan of Pigeon Creek is derived from these formations, they will influence groundwater composition. The Kootenay Group is mostly sandstone interbedded with shale, conglomerate and coal. The Fernie Group is mainly organic black shale and the Sulphur Mountain Formation organic and dolomitic siltstone and shale. Clastic and organic-rich rock contain a wider variety of constituents than limestone or dolomite. Consequently, the total dissolved solids concentrations found at Dead Man's Flats are higher and more diverse than elsewhere in the region. All parameters tested meet the *Guidelines for Canadian Drinking Water Quality*, with the exception of iron for Dead Man's Flats. The average concentration of iron exceeds the aesthetic objective, but is likely more indicative of well, rather than aquifer conditions.

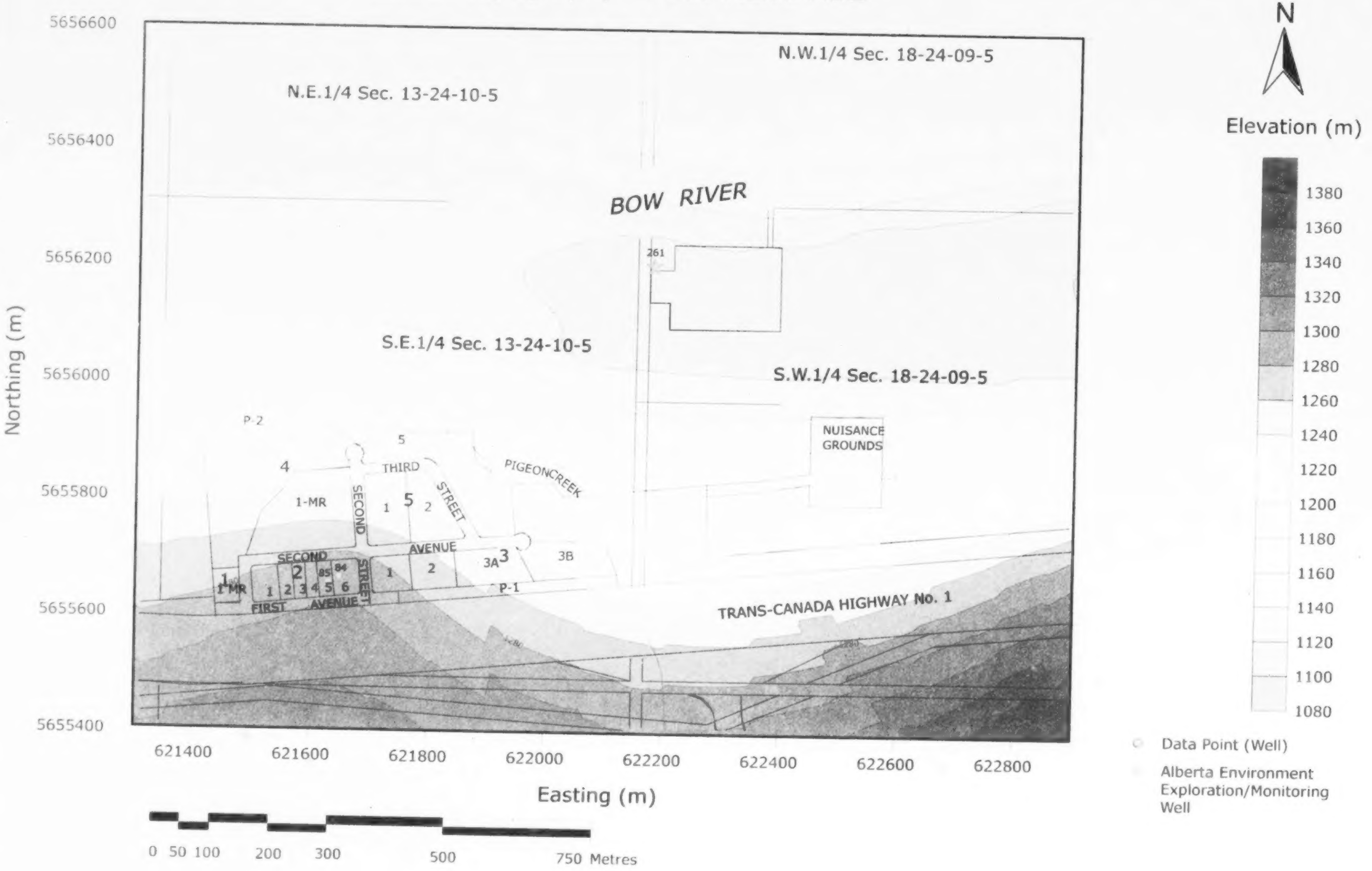
For more information on Dead Man's Flats see Appendices B, C, E and F.

Table F - Average concentrations of major constituents in Groundwater –Dead Man's Flats, vicinity of Dead Man's Flats and Bow River water expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ).
*maximum allowable concentration

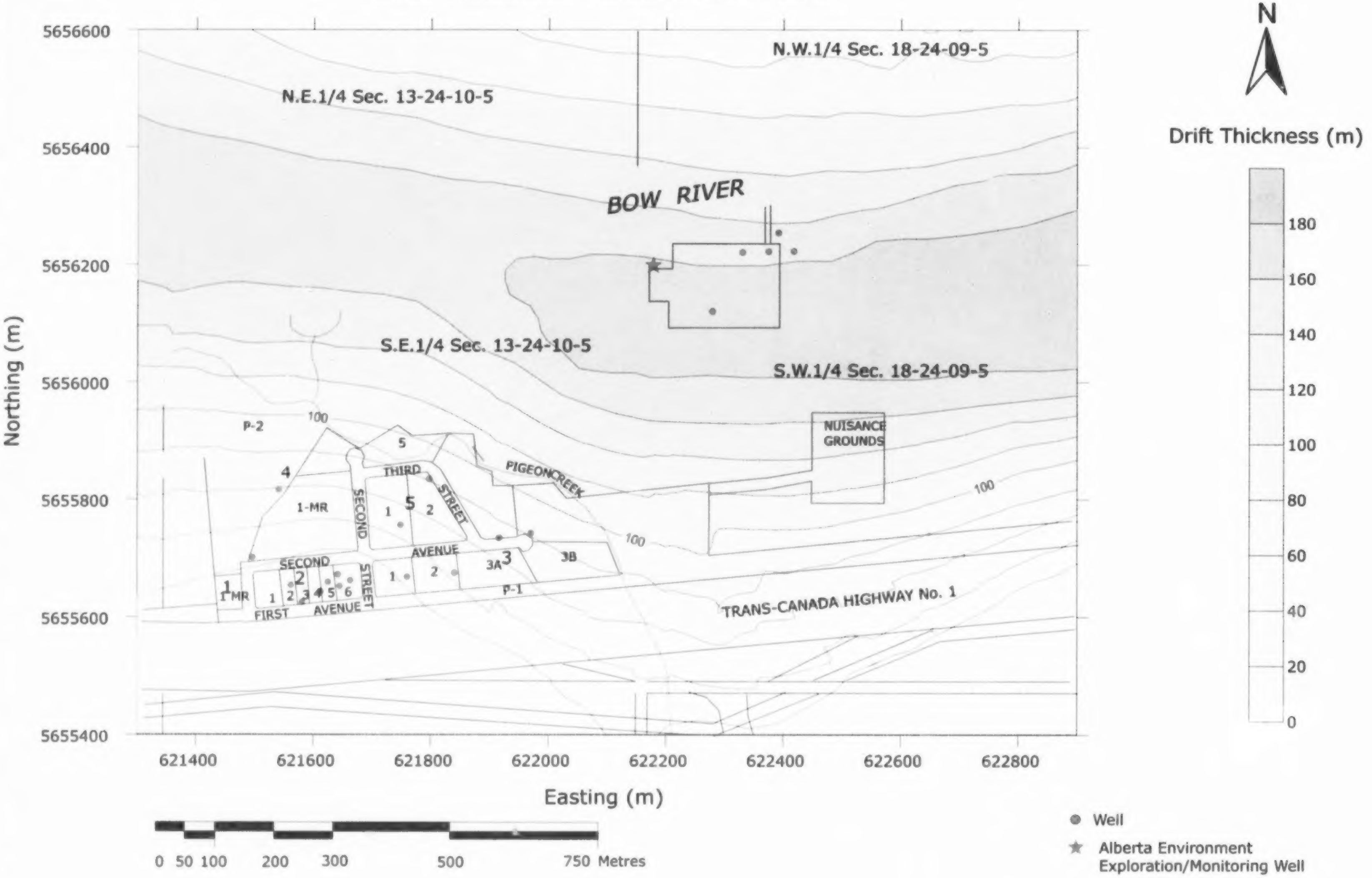
Source	**TDS**	**Hard**	**Ca**	**Mg**	**Na**	**HCO$_3$**	**SO$_4$**	**Cl**	**Fe**	**NO$_3$**	**F**	**n**
Guidelines -CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Bow River	172	165	43	14	2	145	42	2	0.1	0.08		2
Dead Man's Flats	490	130	100	30	25	315	90	45	3.7	0.65	0.15	4
Vicinity	660	410	130	40	25	230	275	35	1.0	0.58	0.54	13


Bedrock Topography - Dead Man's Flats
N
Elevation (m)
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
1180
1160
1140
1120
1100
1080
● Data Point (Well)
★ Alberta Environment Exploration/Monitoring Well
N.W.1/4 Sec. 18-24-09-5
N.E.1/4 Sec. 13-24-10-5
S.E.1/4 Sec. 13-24-10-5
S.W.1/4 Sec. 18-24-09-5
BOW RIVER
361
NUISANCE GROUNDS
TRANS-CANADA HIGHWAY
PIGEONCREEK
THIRD
STREET
SECOND
AVENUE
1-MR
P-2
P-1
3A
3B
Northing (m)
5656600
5656400
5656200
5656000
5655800
5655600
5655400
Easting (m)
621400
621600
621800
622000
622200
622400
622600
622800
0 50 100 200 300 500 750 Metres

Bedrock Topography - Dead Man's Flats


5656600
5656400
5656200
5656000
5655800
5655600
5655400
Northing (m)
621400
621600
621800
622000
622200
622400
622600
622800
Easting (m)
0 50 100 200 300 500 750 Metres
N
N.E.1/4 Sec. 13-24-10-5
N.W.1/4 Sec. 18-24-09-5
BOW RIVER
261
S.E.1/4 Sec. 13-24-10-5
S.W.1/4 Sec. 18-24-09-5
NUISANCE GROUNDS
P-2
5
4
THIRD
PIGEONCREEK
1-MR
SECOND
STREET
1 5 2
SECOND
AVENUE
3A 3
3B
1 MR
1 2 3 4 5 6
85 84
STREET
1
2
P-1
FIRST AVENUE
TRANS-CANADA HIGHWAY No. 1
Elevation (m)
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
1180
1160
1140
1120
1100
1080
Data Point (Well)
Alberta Environment Exploration/Monitoring Well

Drift Thickness - Dead Man's Flats


N.W.1/4 Sec. 18-24-09-5
N.E.1/4 Sec. 13-24-10-5
BOW RIVER
S.E.1/4 Sec. 13-24-10-5
S.W.1/4 Sec. 18-24-09-5
NUISANCE GROUNDS
PIGEON CREEK
TRANS-CANADA HIGHWAY No. 1
P-2
100
4
1-MR
SECOND
5
THIRD
STREET
1
2
AVENUE
3A
3
3B
P-1
SECOND
STREET
FIRST
AVENUE
1 MR
Northing (m)
5656600
5656400
5656200
5656000
5655800
5655600
5655400
Easting (m)
621400
621600
621800
622000
622200
622400
622600
622800
0 50 100 200 300 500 750 Metres
N
Drift Thickness (m)
180
160
140
120
100
80
60
40
20
0
Well
Alberta Environment Exploration/Monitoring Well

Lac des Arcs

The Community

Lac des Arcs is located across the Bow River from Exshaw, on the Trans-Canada Highway. It was developed as an acreage community in the 1970s. There are 83 residential lots wedged between the Bow River and Highway 1. Being newer, its groundwater information is more complete than the other communities of the Bow Valley.

Aquifers

Lac des Arcs is built on the alluvial fan of Heart Creek. Like Dead Man's Flats, the fan lies on top of fluvial deposits of the Bow River, forming an unconfined aquifer of gravel, silt and sand. The water table is approximately 10 m below surface and is comparable to the level of the Bow River, but may be lower in some wells as a result of pumping.

The aquifer's lower boundary occurs at a depth of 30 to 40 m. It is bedrock on the south side of the community and clay till toward the Bow River. The depth to bedrock in Lac des Arcs is not clearly delineated, but it drops dramatically from just below the land surface near the Trans-Canada Highway to over 200 m near the Bow River. Water supplies sufficient for domestic usage are widely available throughout the hamlet. Most wells are between 18 and 30 m deep, rarely penetrating the base of the aquifer. Yields average 100 to 650 m^3/day (15 to 100 igpm) (Table G).

The Calgary Buried Valley aquifer is found at depths exceeding 190 m and may reach 230 m or more. It has been verified in lower Exshaw across the Bow River, but its extent and accessibility beneath Lac des Arcs remains uncertain. Yields from the Calgary Buried Valley aquifer exceed 650 m3/day at Exshaw.

Our exploratory well at the Heart Creek parking lot south of Highway 1 encountered yields exceeding 130 m^3/day from fractured limestone at a depth of 30 m. Heart Creek is situated on the Exshaw Thrust Fault, suggesting that positioning of bedrock wells along a major fault line can significantly improve yield.

Table G – Aquifer characteristics and yield – Lac des Arcs

Aquifer	**Yield m^3/day m**	**Water Level Elevation m**	**Water Level below surface m**	**Base of Aquifer below surface m**
Alluvial	100-650	1292	12	40
Buried Valley	>650	1287	17	230

Groundwater Chemistry

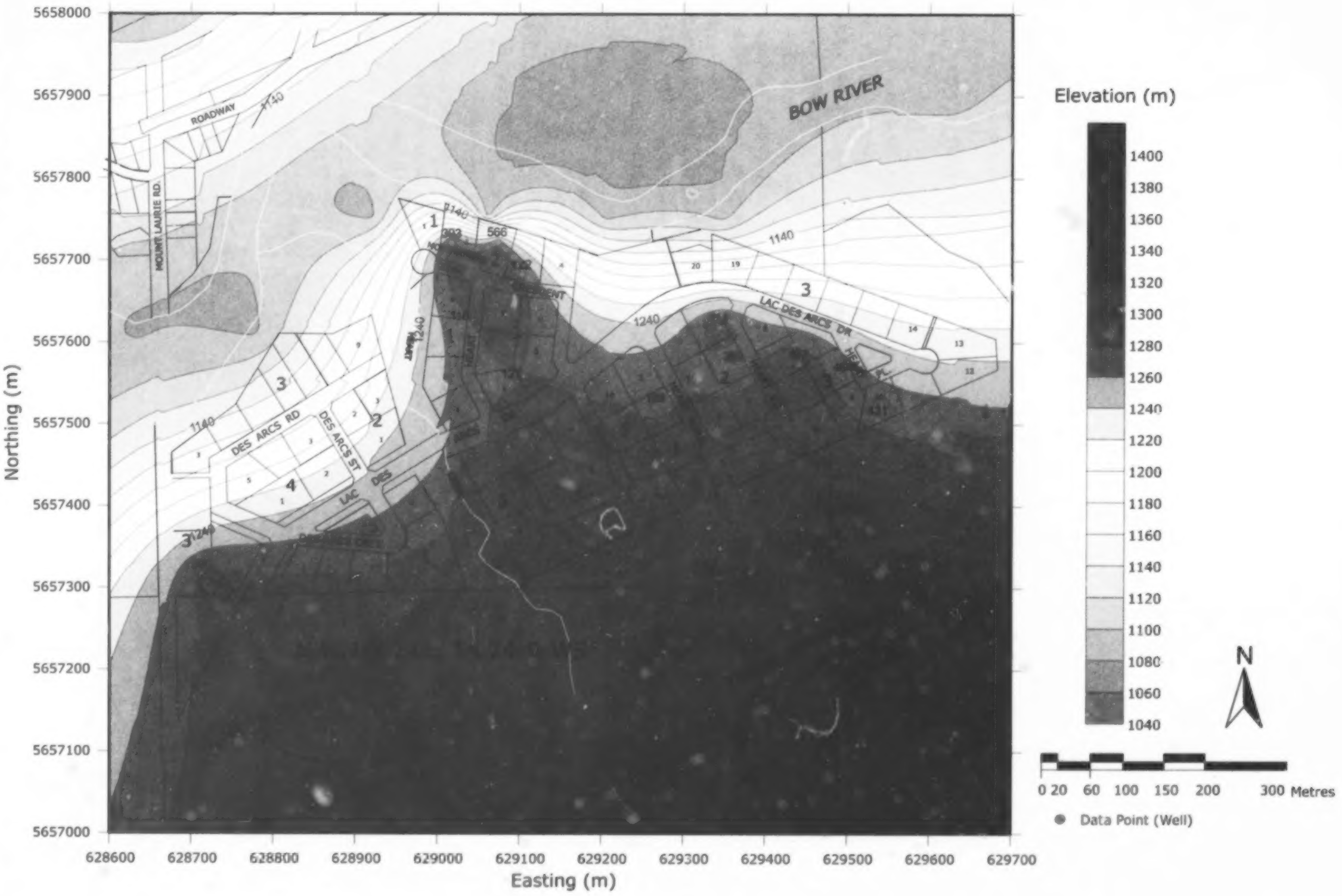
Groundwater in Lac des Arcs is calcium-magnesium-sulphate-bicarbonate type (Table H). Sulphate concentrations are higher relative to other areas of the Bow Valley. Groundwater chemistry in Lac des Arcs is influenced by the geology of the alluvial fan deposited by Heart Creek. The Heart Creek drains across the Palliser Formation, consisting of black, organic rich limestone with dolomite ($CaMgCO_3$) and anhydrite ($CaSO_4$) beds near its base. As a consequence, groundwater in the Lac des Arcs area contains higher concentrations of calcium, sulphate and total dissolved solids than most other parts of the Bow Valley. Water samples from the community show little variation, indicating it is relatively pristine. All parameters tested meet the *Guidelines for Canadian Drinking Water Quality*, with the exception of iron. The average concentration of iron exceeds the aesthetic objective, but is likely more indicative of well, rather than aquifer conditions.

For more information on Lac des Arcs see Appendices B, C and F.

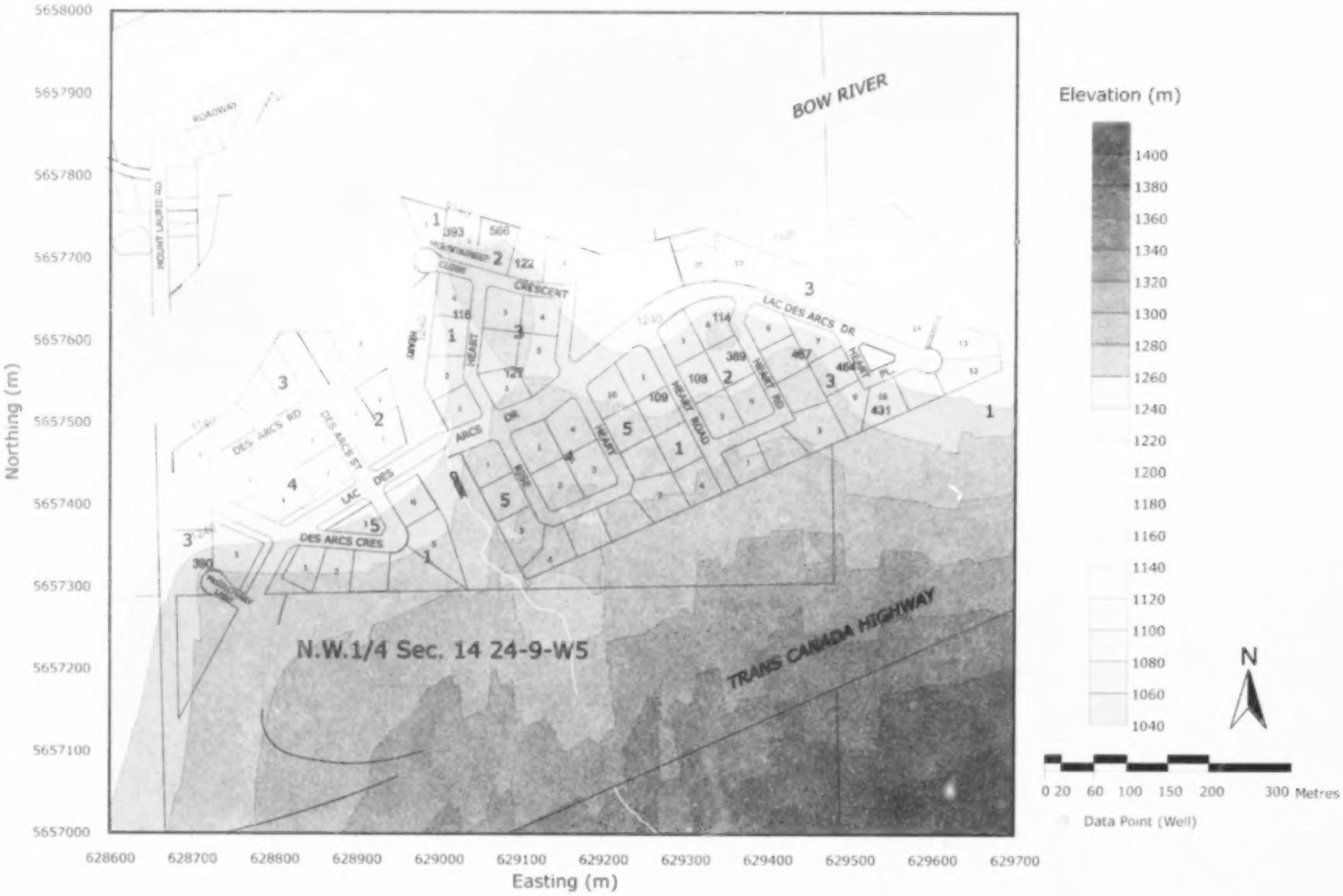
Table H - Average concentrations of major constituents in Groundwater –Lac des Arcs, Buried Valley Aquifer, Heart Creek bedrock well and Bow River water expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ).
*maximum allowable concentration

Source	**TDS**	**Hard**	**Ca**	**Mg**	**Na**	**HCO_3**	**SO_4**	**Cl**	**Fe**	**NO_3**	**F**	**n**
Guidelines - CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Bow River	172	165	43	14	2	145	42	2	0.1	0.08		2
Lac des Arcs	390	200	86	29	4	178	173	6	0.4	0.29	0.5	34
Buried Valley	320	280	72	26	3	177	132	1	0.5	.004	0.6	1
Heart Creek well	365	330	80	30	2	188	153	5	0.3	0.24	0.5	1

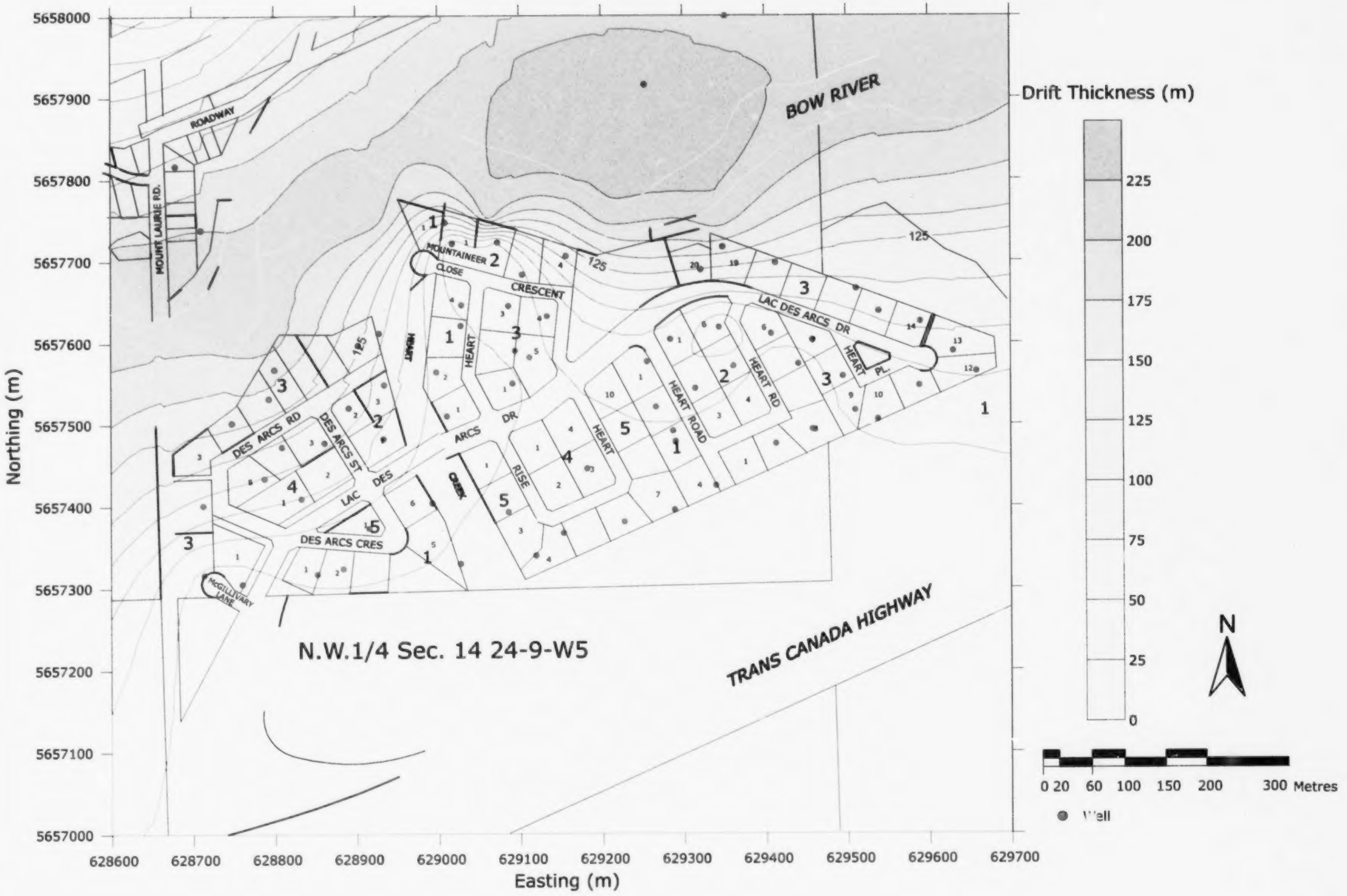
Bedrock Topography - Lac des Arcs


Northing (m)
5658000
5657900
5657800
5657700
5657600
5657500
5657400
5657300
5657200
5657100
5657000
Easting (m)
628600
628700
628800
628900
629000
629100
629200
629300
629400
629500
629600
629700
BOW RIVER
ROADWAY
MOUNT LAURIE RD.
DES ARCS RD
DES ARCS ST
LAC DES
LAC DES ARCS DR
HEART
CRESCENT
1140
1240
566
Elevation (m)
1400
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
1180
1160
1140
1120
1100
1080
1060
1040
N
0 20 60 100 150 200 300 Metres
● Data Point (Well)

Bedrock Topography - Lac des Arcs


BOW RIVER
TRANS CANADA HIGHWAY
N.W.1/4 Sec. 14 24-9-W5
LAC DES ARCS DR
HEART RD
HEART ROAD
HEART PL
HEART CRESCENT
MOUNTAINEER CLOSE
ARCS DR
DES ARCS RD
DES ARCS ST
LAC DES
DES ARCS CRES
RISE
MOUNT LAURIE RD
ROADWAY
Northing (m)
5658000
5657900
5657800
5657700
5657600
5657500
5657400
5657300
5657200
5657100
5657000
Easting (m)
628600
628700
628800
628900
629000
629100
629200
629300
629400
629500
629600
629700
Elevation (m)
1400
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
1180
1160
1140
1120
1100
1080
1060
1040
N
0 20 60 100 150 200 300 Metres
Data Point (Well)

Drift Thickness - Lac des Arcs


BOW RIVER
TRANS CANADA HIGHWAY
N.W.1/4 Sec. 14 24-9-W5
ROADWAY
MOUNT LAURIE RD.
MOUNTAINEER CLOSE
CRESCENT
HEART
LAC DES ARCS DR
HEART PL.
HEART RD
HEART ROAD
DES ARCS RD
DES ARCS ST
LAC DES ARCS DR
RISE
CREEK
DES ARCS CRES
MCGILLIVARY LANE
125
Northing (m)
5658000
5657900
5657800
5657700
5657600
5657500
5657400
5657300
5657200
5657100
5657000
Easting (m)
628600
628700
628800
628900
629000
629100
629200
629300
629400
629500
629600
629700
Drift Thickness (m)
225
200
175
150
125
100
75
50
25
0
N
0 20 60 100 150 200 300 Metres
● Well

Exshaw

The Community

Exshaw is situated on Highway 1A and the CPR mainline. The hamlet was established in 1910 by the Canada Cement Company, now known as Lafarge Canada Inc., and grew around the mining industry. Local miners and processors of industrial minerals include Lafarge Canada Inc. (cement), Graymont Industries (lime), Baymag (magnesium) and Burnco (aggregates), who are significant contributors to the local economy. Much of the original hamlet was removed in 1974 to accommodate an expansion by Lafarge, and was relocated to the east side of the community.

Aquifers

Exshaw is served by domestic wells. Drilling reports for wells drilled prior to 1970 were rarely submitted to Alberta Environment and reports for newer wells that were submitted seldom gave a specific address, leaving the data for the area incomplete. A number of homes share common wells. The northern part of Exshaw (Knowlerville) uses water piped from Exshaw Creek, where groundwater supplies could not be obtained from the thin layer of low permeability drift.

Exshaw is built on the coalescing alluvial fans of Exshaw Creek and Jura Creek. The alluvial fans form an unconfined aquifer, overlying bedrock in the north and fluvial deposits of the Bow River to the south. Surficial deposits thicken from a few metres in Knowlerville to at least 220 m near the Bow River in lower Exshaw. Most wells are relatively shallow, often in the range of 15 to 30 m as the water table is 8 to 20 m below surface. Yields in the range of 30 to 650 m^3/day (5-100 igpm) may be obtainable (Table I), decreasing toward the north of the hamlet.

We drilled two exploratory wells in Exshaw, one near the Bow River in lower Exshaw and one at Knowlerville. The exploratory well in lower Exshaw penetrated the surface gravel aquifer 14 m thick, followed by 175 m of clay and 26 m of a lower gravel aquifer, overlying black shale bedrock. The well was completed in the lower aquifer and was tested at a flow rate exceeding 2000 m^3/day. The static water level is close to that of the Bow River. The well confirmed the presence of the Calgary Buried Valley aquifer in lower Exshaw as an alternative water source. Because of its depth and isolation from the surface by a thick clay layer, it has a very low risk of

Table I - Aquifer Charactersitics and Yield - Exshaw

Aquifer	Yield m^3/day m	Water Level Elevation m	Water Level below surface m	Base of Aquifer below surface m
Exshaw	30 to 650	1292	8 - 20	15 - 45
Buried Valley	2000+	1287	3	220

contamination. The well was added to Alberta Environment's monitoring well network in 2001. Lafarge Canada and Graymont Industries both have wells that terminate in thick intervals of clay drift. It is possible that the Calgary Buried Valley aquifer is found at depth at these sites.

At Knowlerville, we obtained 25 m^3/day of water from bedrock at a contact zone between the Palliser Formation and the Rundle Group at a depth of 37 m. Water quality was poor. Apart from this zone, there was no measurable yield from bedrock. It may be possible to locate improved yields from bedrock by drilling along the trace of a major fault as was the case with our exploratory well across the river at Heart Creek.

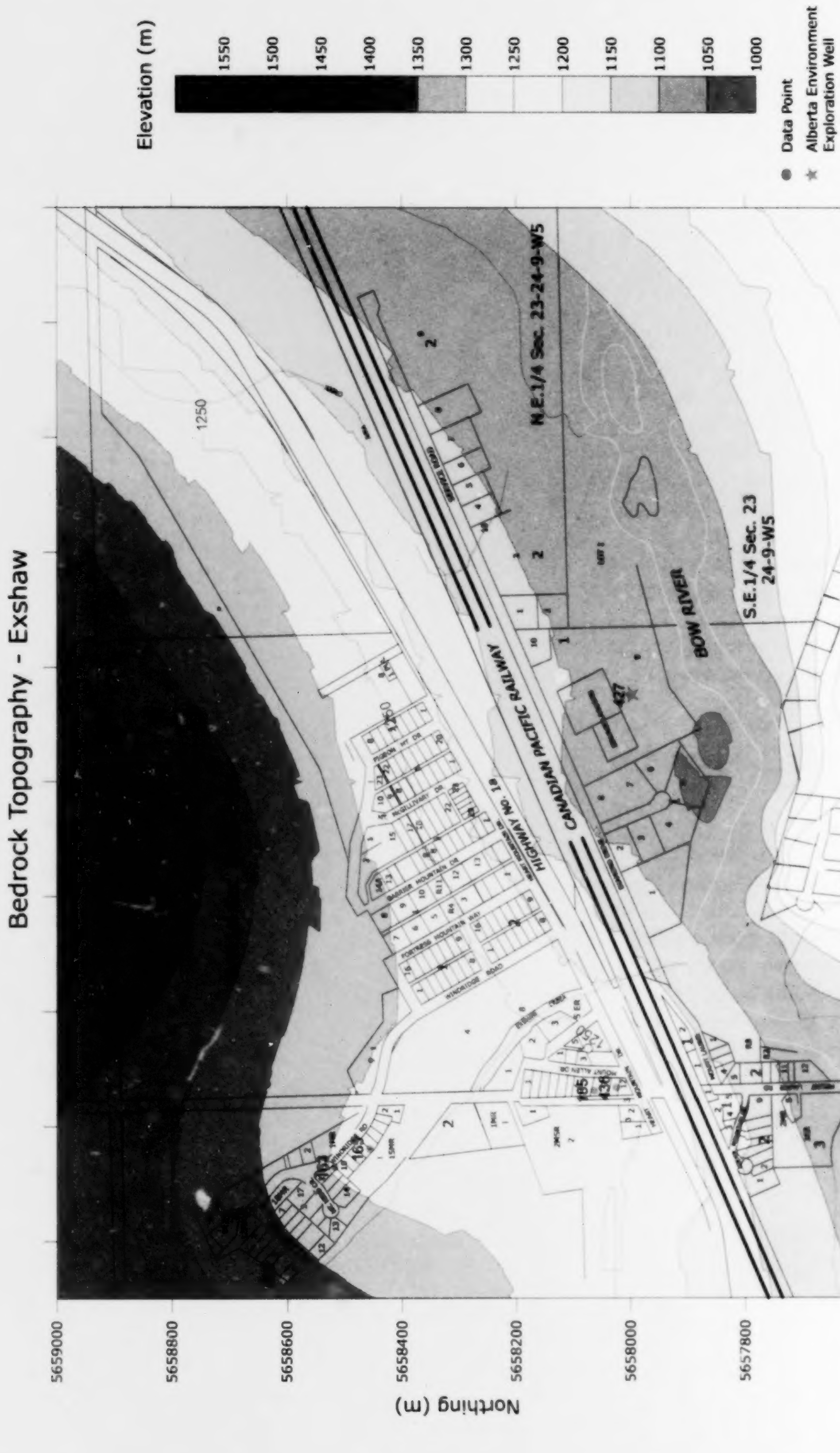
The water is calcium-magnesium-bicarbonate-sulphate type (Table J) in both the near surface alluvial aquifer and the buried valley aquifer. The alluvial fan of Exshaw Creek is derived primarily from the Etherington Formation, whereas at Lac des Arcs the source is the Palliser Formation, accounting for differences in water type between the neighbouring communities.

All parameters tested meet the Guidelines for Canadian Drinking Water Quality, with the exception of iron. The average concentration of iron exceeds the aesthetic objective, but is likely more indicative of specific wells, rather than aquifer conditions. Higher than background concentrations of nitrates suggest that groundwater quality at some sites may have been affected by external inputs.

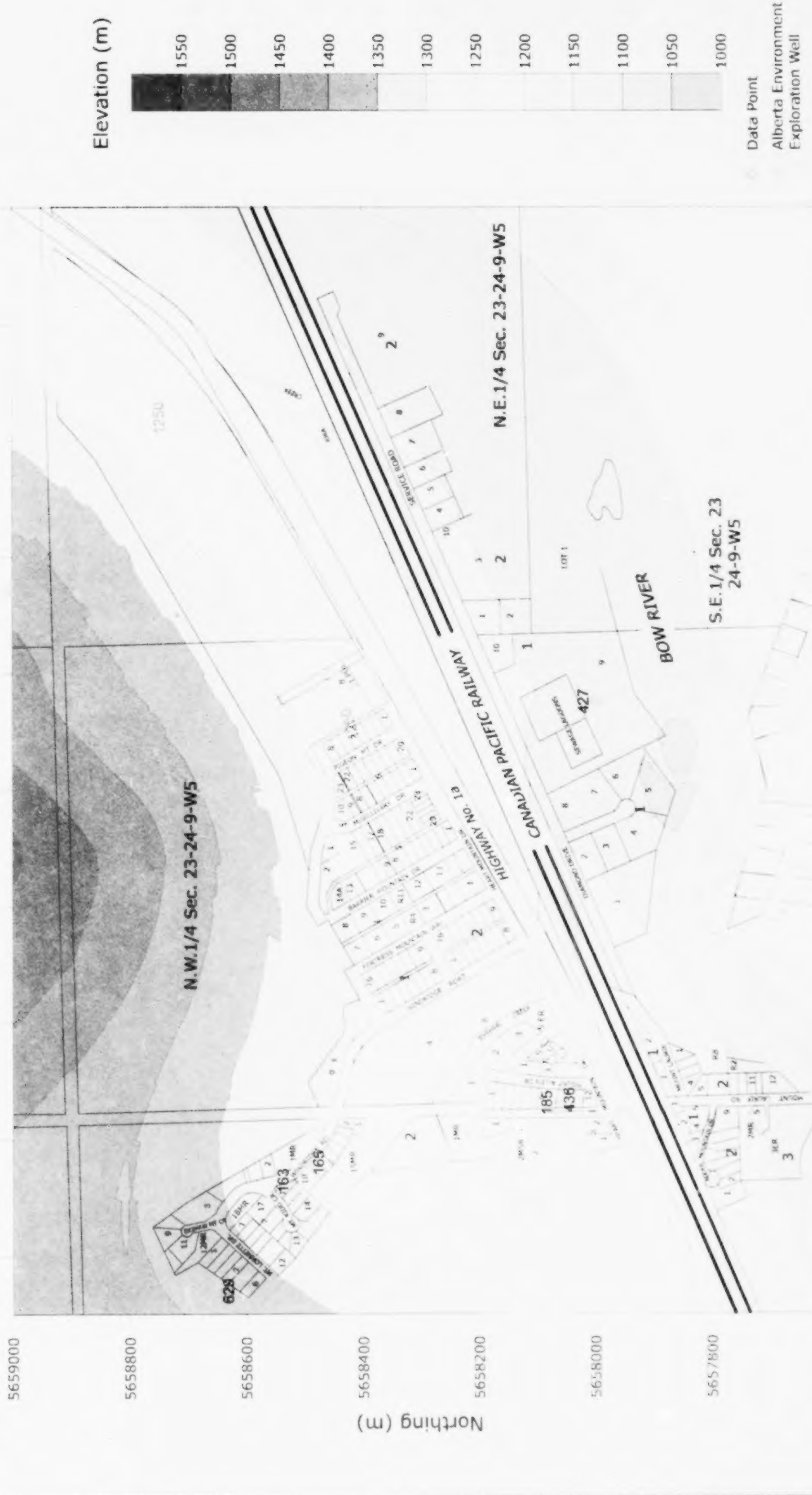
For more information on Exshaw see Appendices B, C, E and F.

Table J - Average concentrations of major constituents in Groundwater –Exshaw, Upper and lower aquifers and Bow River water expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ).
*maximum allowable concentration

Source	**TDS**	**Hard**	**Ca**	**Mg**	**Na**	**HCO_3**	**SO_4**	**Cl**	**Fe**	**NO_3**	**F**	**n**
Guidelines - CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Bow River	172	165	43	14	2	145	42	2	0.1	0.08		2
Exshaw	255	143	63	19	4	210	50	4	1	1.9	0.2	22
Buried Valley	320	280	72	26	3	177	132	1	0.5	.004	0.6	1
Knowlerville	340	330	96	23	2	312	61	2	1.4	0.25	0.3	1

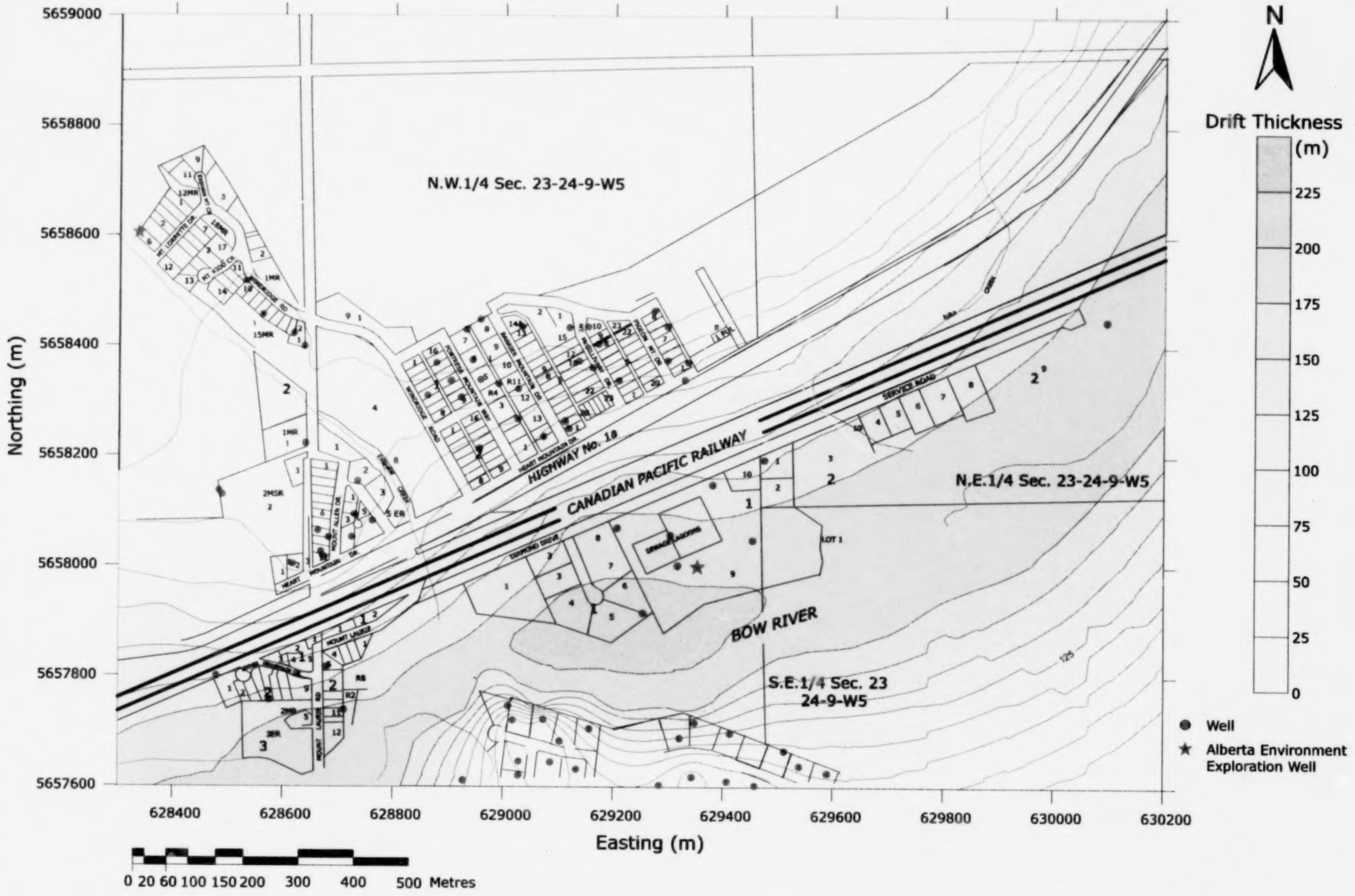
Bedrock Topography - Exshaw
Elevation (m)
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
● Data Point
★ Alberta Environment Exploration Well
Northing (m)
5659000
5658800
5658600
5658400
5658200
5658000
5657800
5657600
Easting (m)
628400
628600
628800
629000
629200
629400
629600
629800
630000
630200
0 20 60 100 150 200 300 400 500 Metres
1250
HIGHWAY NO. 1A
CANADIAN PACIFIC RAILWAY
BOW RIVER
N.E.1/4 Sec. 23-24-9-W5
S.E.1/4 Sec. 23 24-9-W5

Bedrock Topography - Exshaw



Elevation (m)
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
Data Point
Alberta Environment Exploration Well
N.W.1/4 Sec. 23-24-9-W5
N.E.1/4 Sec. 23-24-9-W5
S.E.1/4 Sec. 23 24-9-W5
HIGHWAY No. 1A
CANADIAN PACIFIC RAILWAY
BOW RIVER
1250
628
163
165
185
436
427
Northing (m)
5659000
5658800
5658600
5658400
5658200
5658000
5657800
5657600
Easting (m)
628400
628600
628800
629000
629200
629400
629600
629800
630000
630200
0 20 60 100 150 200 300 400 500 Metres

Drift Thickness - Exshaw


N
Drift Thickness (m)
225
200
175
150
125
100
75
50
25
0
● Well
★ Alberta Environment Exploration Well
Northing (m)
5659000
5658800
5658600
5658400
5658200
5658000
5657800
5657600
Easting (m)
628400
628600
628800
629000
629200
629400
629600
629800
630000
630200
0 20 60 100 150 200 300 400 500 Metres
N.W.1/4 Sec. 23-24-9-W5
N.E.1/4 Sec. 23-24-9-W5
S.E.1/4 Sec. 23 24-9-W5
CANADIAN PACIFIC RAILWAY
HIGHWAY No. 1A
BOW RIVER
SERVICE ROAD
WINDRIDGE ROAD
HEART MOUNTAIN DR.
MOUNT ALLEN DR.
MOUNT LAURIER
DIAMOND DRIVE
LOT 1
125

Evan Thomas-Kananaskis Village

The Community

Kananaskis Country was designated in 1977 as a multiuse recreation area. Prior to development, Alberta Environment commissioned a groundwater exploration program and utilities study (Hydrogeological Consultants, 1978). Most of the facilities in the valley are located in the Evan-Thomas area. The major facilities of Kananaskis Village, the Kananaskis Country Golf Course, and Mount Kidd R.V. Park are on a central water supply from wells located on the golf course. The Nakiska Ski Hill, Boundary Ranch, Sundance Lodges, Ribbon Creek Hostel and the Emergency Services Centre operate their own wells.

Aquifers

The Evan-Thomas / Kananaskis Village area is located where the Kananaskis Valley coincides with the Mount Allan Syncline. As a result, the valley bottom is around 3 km wide, compared to 1 km wide elsewhere. It is lined with drift deposits 15 to 35 m thick, consisting mainly of gravel originating from the alluvial fan of Evan-Thomas Creek, and fluvial deposits from the Kananaskis River. A coarse stony till drapes the mountainsides. The upper bedrock formations are Jurassic Kootenay Group and Triassic Spray River Group consisting of sandstone, siltstone, silty carbonates, black shale and coal.

Floodplain deposits form a highly permeable unconfined aquifer where yields exceeding 400 igpm (2600 m^3/day) are possible (Table K). The gradient of the Kananaskis Valley is relatively steep, dropping 100 m over a distance of 10 km. The valley aquifer and water table parallel the surface gradient.

Groundwater Chemistry

The water type is dominantly calcium-magnesium-bicarbonate, with a few samples reporting as calcium-magnesium-bicarbonate-sulphate type water (Table L). The water tested meets the Guidelines for Canadian Drinking Water Quality, with the exception of iron. Iron exceeds the aesthetic objective of 0.3 mg/L, but is likely related to well maintenance rather than from the aquifer. The floodplain aquifer is fairly open to the surface and could become contaminated through carelessness. Care should be taken with sewage treatment.

Table K- Aquifer Characteristics and Yield – Evan Thomas

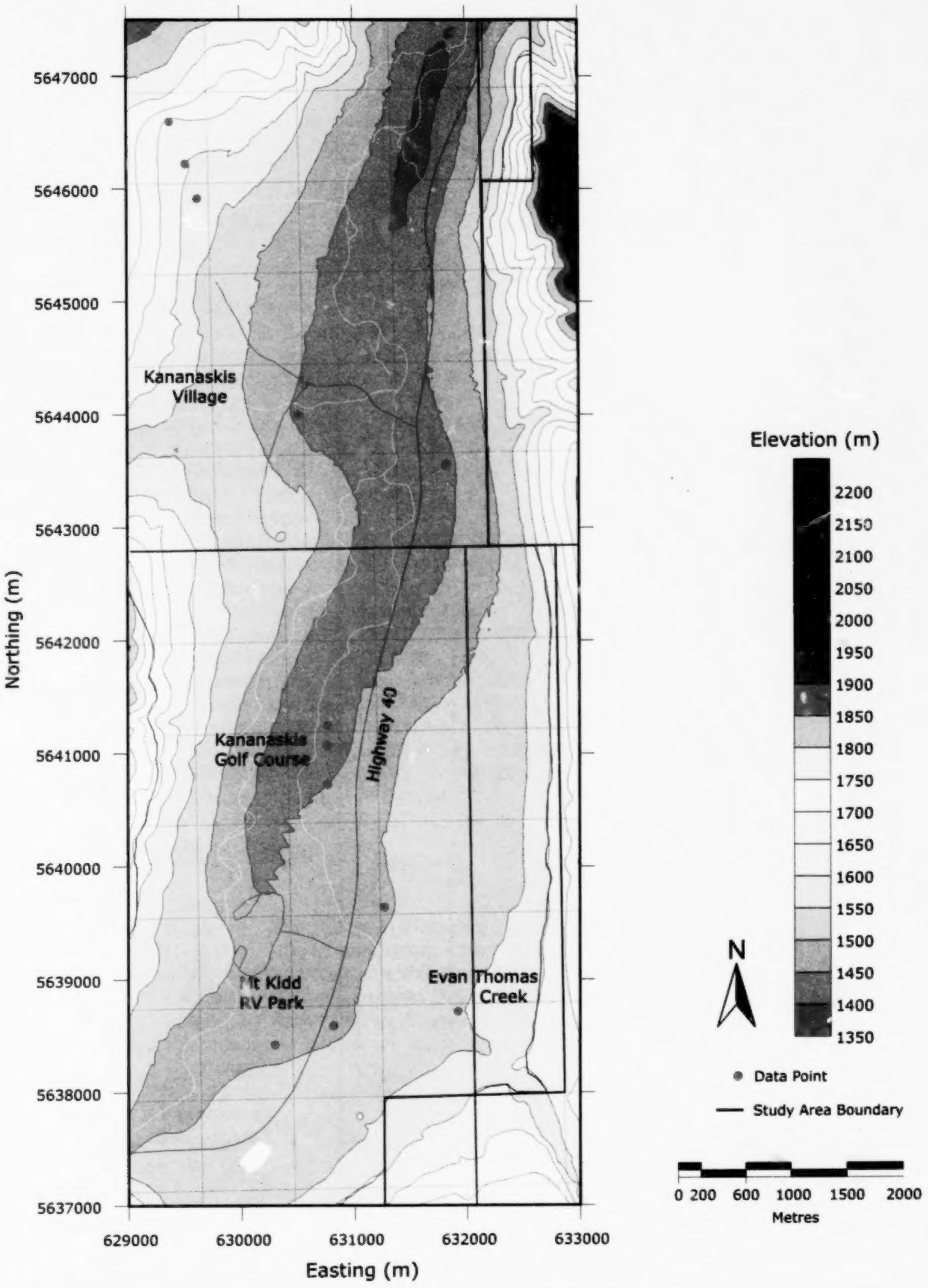
Aquifer	Yield m^3/day m	Water Level Elevation m	Water Level below surface m	Base of Aquifer below surface m
Exshaw	30 to 650	1292	8 - 20	15 - 45
Buried Valley	2000+	1287	3	220

For more information on Evan-Thomas/Kananaskis see Appendices B and C.

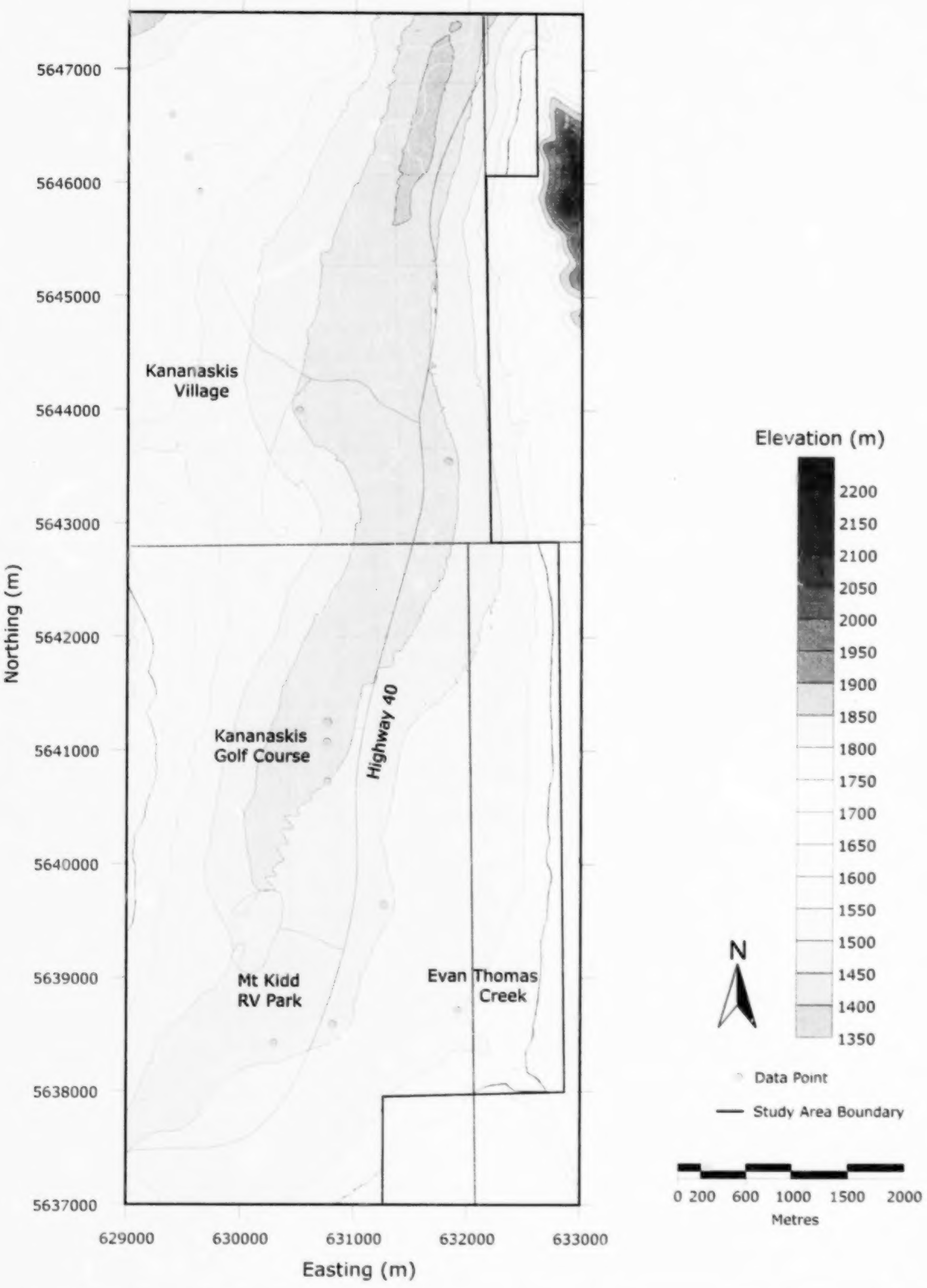
Table L - Average concentrations of major constituents in Groundwater –Evan Thomas expressed in mg/L, and number of samples "n" and compared to maximum aesthetic objective for Guidelines for Canadian Drinking Water Quality (CDWQ).
*maximum allowable concentration

Source	**TDS**	**Hard**	**Ca**	**Mg**	**Na**	**HCO_3**	**SO_4**	**Cl**	**Fe**	**NO_3**	**F**	**n**
Guidelines-CDWQ	500	500	200	150	200	700	500	250	0.3	45*	1.5*	
Floodplain	196	72	48	16	5	194	32	2	1.0	0.27	0.18	23

Bedrock Topography - Evan Thomas / Kananaskis Valley

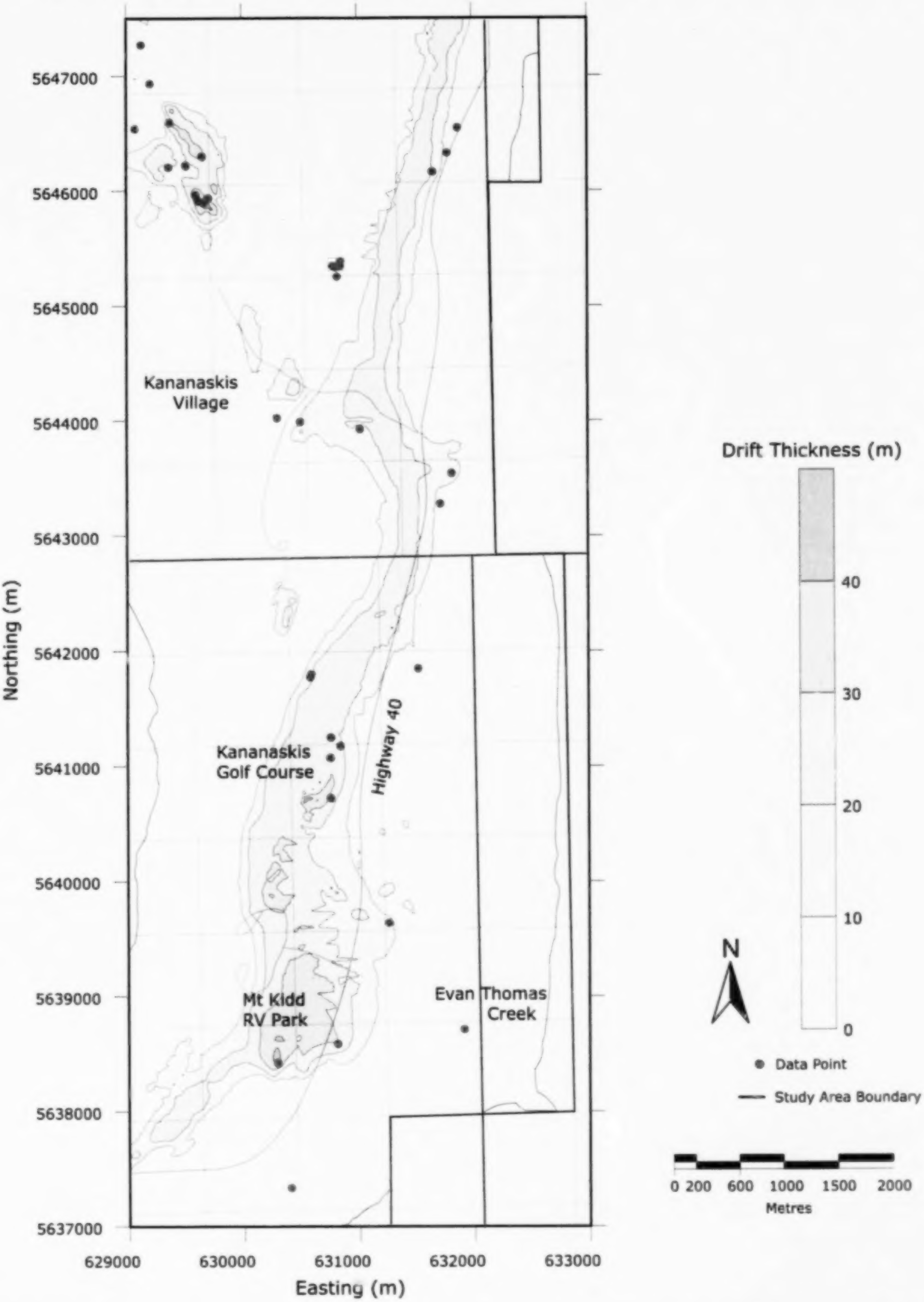

Kananaskis Village
Kananaskis Golf Course
Highway 40
Mt Kidd RV Park
Evan Thomas Creek
Northing (m)
5647000
5646000
5645000
5644000
5643000
5642000
5641000
5640000
5639000
5638000
5637000
Easting (m)
629000
630000
631000
632000
633000
Elevation (m)
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
N
Data Point
Study Area Boundary
0 200 600 1000 1500 2000
Metres

Bedrock Topography - Evan Thomas / Kananaskis Valley



Kananaskis Village
Kananaskis Golf Course
Highway 40
Mt Kidd RV Park
Evan Thomas Creek
5647000
5646000
5645000
5644000
5643000
5642000
5641000
5640000
5639000
5638000
5637000
Northing (m)
629000
630000
631000
632000
633000
Easting (m)
Elevation (m)
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
N
Data Point
Study Area Boundary
0 200 600 1000 1500 2000
Metres

Drift Thickness - Evan Thomas / Kananaskis Valley


Northing (m)
5647000
5646000
5645000
5644000
5643000
5642000
5641000
5640000
5639000
5638000
5637000
Easting (m)
629000
630000
631000
632000
633000
Kananaskis Village
Kananaskis Golf Course
Highway 40
Mt Kidd RV Park
Evan Thomas Creek
Drift Thickness (m)
40
30
20
10
0
N
● Data Point
— Study Area Boundary
0 200 600 1000 1500 2000
Metres

Appendix E

Exploration Hole Logs

Test Hole Location Map
Test Hole Table

Lithology Logs

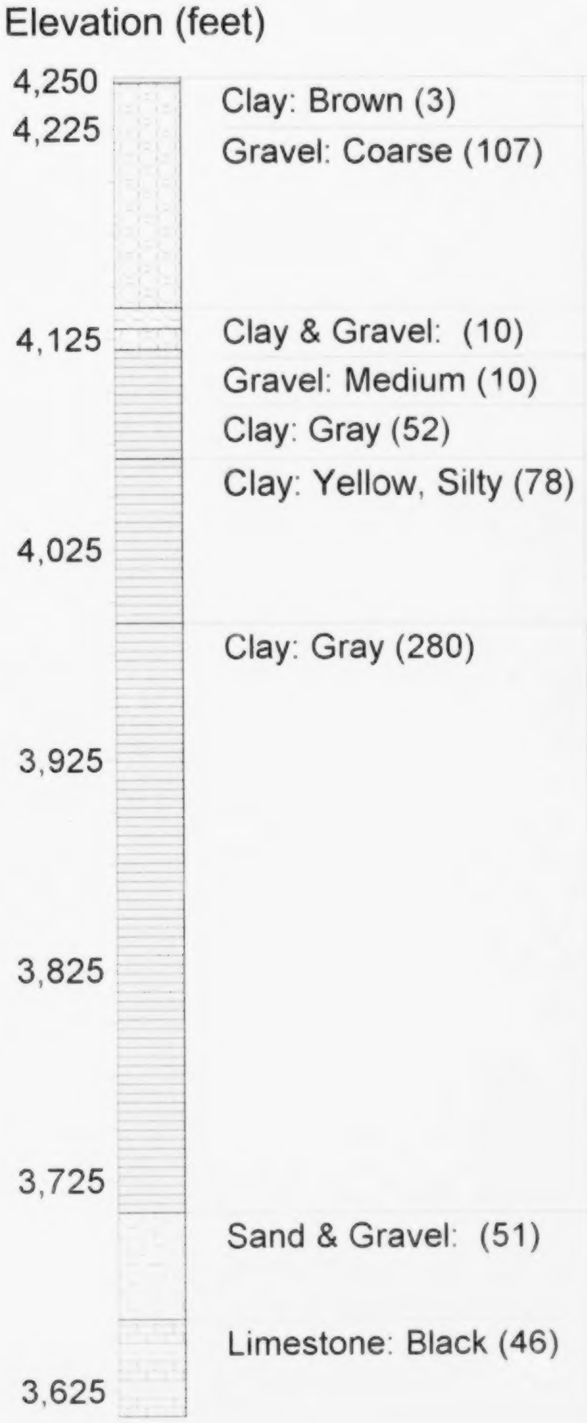
Test Hole 1 – Dead Man's Flats – WEPA #261
Test Hole 2 – Canmore Travel Booth – WEPA #428
Test Hole 3 – Rafter Six Church – WEPA 443
Test Hole 4 – Exshaw Lagoons – WEPA 427
Test Hole 5 – Bow Valley South – WEPA 444
Test Hole 6 – Rafter Six #2 – WEPA 442
Test Hole 7 – Yamnuska #1 (Parking Lot) – WEPA 487
Test Hole 8 – Heart Creek – WEPA 490
Test Hole 9 – Mount Shark – WEPA 491
Test Hole 10 – Buller Day Use (West Lot) – WEPA 493
Test Hole 11 – Driftwood Day Use – WEPA 496
Test Hole 12 – Spray Ranger Station – WEPA 497
Test Hole 13 – Yamnuska #2 (Entrance Road) – WEPA 487
Test Hole 14 – Yamnuska #3 (Gravel Pit) – WEPA 488
Test Hole 15 – Goat Creek – WEPA 498
Test Hole 16 – Spray Lakes Day Use – WEPA 495
Test Hole 17 – Buller Day Use (East Lot) – WEPA 494
Test Hole 18 – Canmore Water Treatment Plant – WEPA 628
Test Hole 19 – Yamnuska #4 (Quarry Road) – WEPA 665
Test Hole 20 – Exshaw (Knowlerville) – WEPA 629
Test Hole 21 – Harvie Heights – WEPA 627

Geophysical Logs

Test Hole 2 (Gamma)
Test Hole 3 (Gamma / Spontaneous Potential / Resistivity)
Test Hole 4 (Gamma / Spontaneous Potential / Resistivity)
Test Hole 5 (Gamma / Spontaneous Potential / Resistivity)
Test Hole 6 (Gamma / Spontaneous Potential / Resistivity)
Test Hole 7 (Gamma / Spontaneous Potential / Resistivity)
Test Hole 8 (Gamma)
Test Hole 9 (Gamma)
Test Hole 11 (Gamma)
Test Hole 12 (Gamma)
Test Hole 19 (Gamma)
Test Hole 20 (Gamma)
Test Hole 21 (Gamma)

Table of Exploration Holes

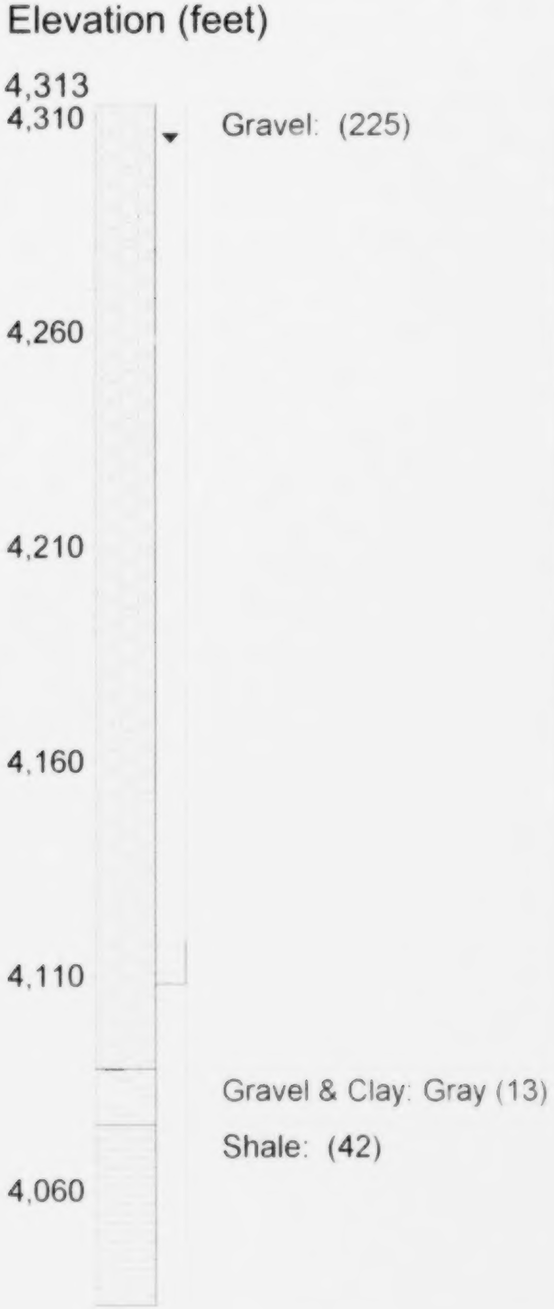
Test Hole #	Well Survey #	Name	Location	Status	Depth	Formation
1	261	Dead Man's Flats	SW-18-24-09W5	Observation Well #758	194.2	Buried Valley
2	428	Canmore Travel Booth	NW-05-25-10W5	Observation Well #760	85.3	Buried Valley
3	443	Rafter Six #1-Church	NE-27-24-08W5	Reclaimed	67.1	Bedrock
4	427	Exshaw Lagoons	SW-23-24-09W5	Observation Well #759	201.2	Buried Valley
5	444	Bow Valley South	02-27-24-08W5	Reclaimed	24.4	Bedrock
6	442	Rafter Six #2	NE-27-24-08W5	Abandoned	30.5	Drift
7	487	Yamnuska #1 (Parking Lot)	NW-08-25-08W5	Well	45.7	Drift
8	490	Heart Creek	NE-15-24-09W5	Well	36.6	Fractured Bedrock
9	491	Mount Shark	NW-07-22-10W5	Well	38.1	Bedrock
10	493	Buller #1 (West Lot)	SW-17-22-10W5	Reclaimed	19.8	Bedrock
11	496	Driftwood	SW-18-24-09W5	Observation Well #761	24.4	Drift
12	497	Spray Ranger Station	SE-31-23-10W5	Observation Well #762	32.9	Drift
13	487	Yamnuska #2 (Entrance)	NW-05-25-08W5	Reclaimed	18.3	Drift
14	488	Yamnuska #3 (Gravel Pit)	NE-08-25-08W5	Reclaimed	24.4	Drift
15	498	Goat Creek	NW-24-24-11W5	Observation Well #763	61.0	Shattered Bedrock
16	495	Spray Lakes Day Use	SW-03-23-10W5	Well	36.6	Drift
17	494	Buller #2 (East Lot)	SW-17-22-10W5	Reclaimed	67.1	Bedrock
18	628	Canmore Water Treatment Plant	11-28-24-10W5	Well	192.0	Buried Valley
19	665	Yamnuska #4 (Quarry Road)	12-08-25-08W5	Well	33.5	Drift
20	629	Exshaw-Knowlerville	16-22-24-09W5	Well	73.2	Bedrock
21	627	Harvie Heights	SE-19-25-10W5	Observation Well #764	59.1	Drift



Test Hole 1

Well Number 261: Dead Man's Flats
▾ Water Level
Completion Interval
(30) Thickness of interval in feet

Location: SW-18-24-09W5
Surface Elevation: 1296 m
Depth:194.15 m
Water Level elev.: 1278 m
Completion Interval: 163.7-194.2
Driller: Alken Basin
Date: Oct 1, 1999
Monitoring Well # 758


Elevation (feet)
4,313
4,310
4,260
4,210
4,160
4,110
4,060
Gravel: (225)
Gravel & Clay: Gray (13)
Shale: (42)

Test Hole 2

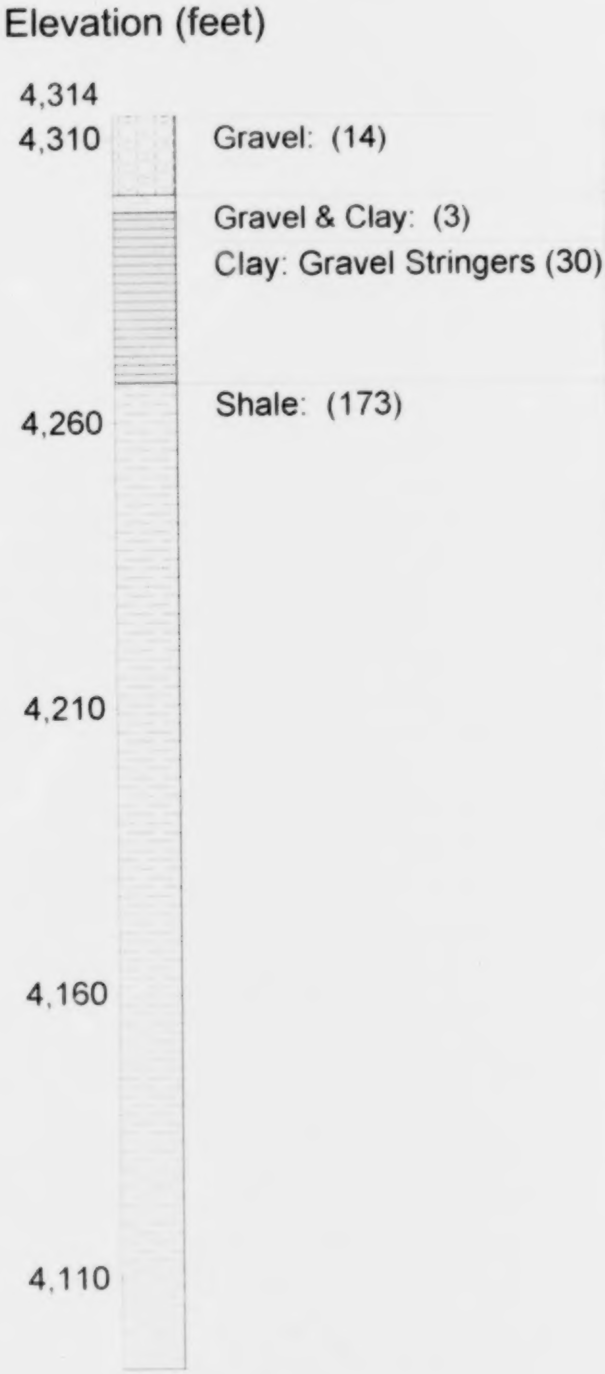
Well Number 428: Canmore Travel Booth

▾ Water Level

Completion Interval

(30) Thickness of interval in feet

Location: NW-05-25-10W5
Elevation: 1314.6 m
Depth:85.34 m
Water Level elev.: 1311 m
Completion Interval: 59.4-62.5 m
Driller: Alken Basin
Date: Aug 23, 2000
Monitoring Well # 760


Elevation (feet)
4,314
4,310
Gravel: (14)
Gravel & Clay: (3)
Clay: Gravel Stringers (30)
Shale: (173)
4,260
4,210
4,160
4,110

Test Hole 3

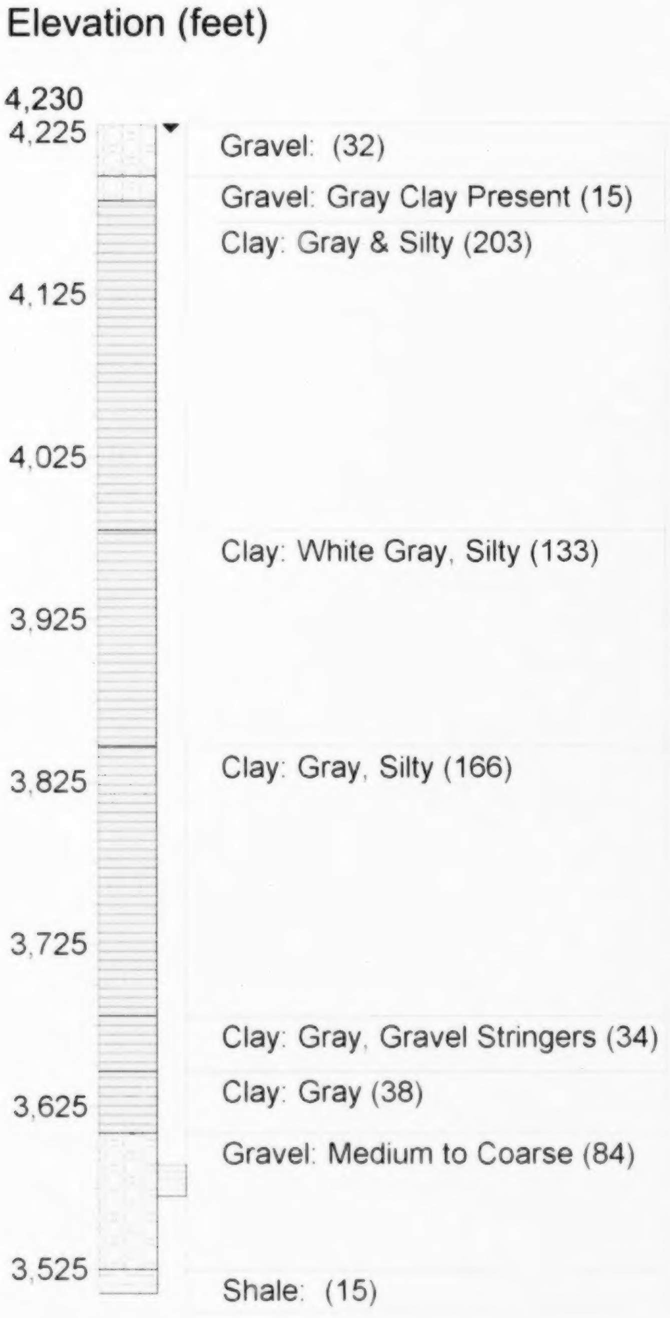
Well Number 443: Rafter Six Church

▾ Water Level

Completion Interval

(30) Thickness of interval in feet

Location: NE-27-24-08W5
Elevation: 1314.9 m
Depth:67.05 m
Water Level elev.: dry
Completion Interval:
Driller: Alken Basin
Date: Aug 25, 2000
Reclaimed


Elevation (feet)
4,230
4,225
4,125
4,025
3,925
3,825
3,725
3,625
3,525
Gravel: (32)
Gravel: Gray Clay Present (15)
Clay: Gray & Silty (203)
Clay: White Gray, Silty (133)
Clay: Gray, Silty (166)
Clay: Gray, Gravel Stringers (34)
Clay: Gray (38)
Gravel: Medium to Coarse (84)
Shale: (15)

Test Hole 4

Well Number 427: Exshaw Lagoons

▾ Water Level

Completion Interval

(30) Thickness of interval -feet

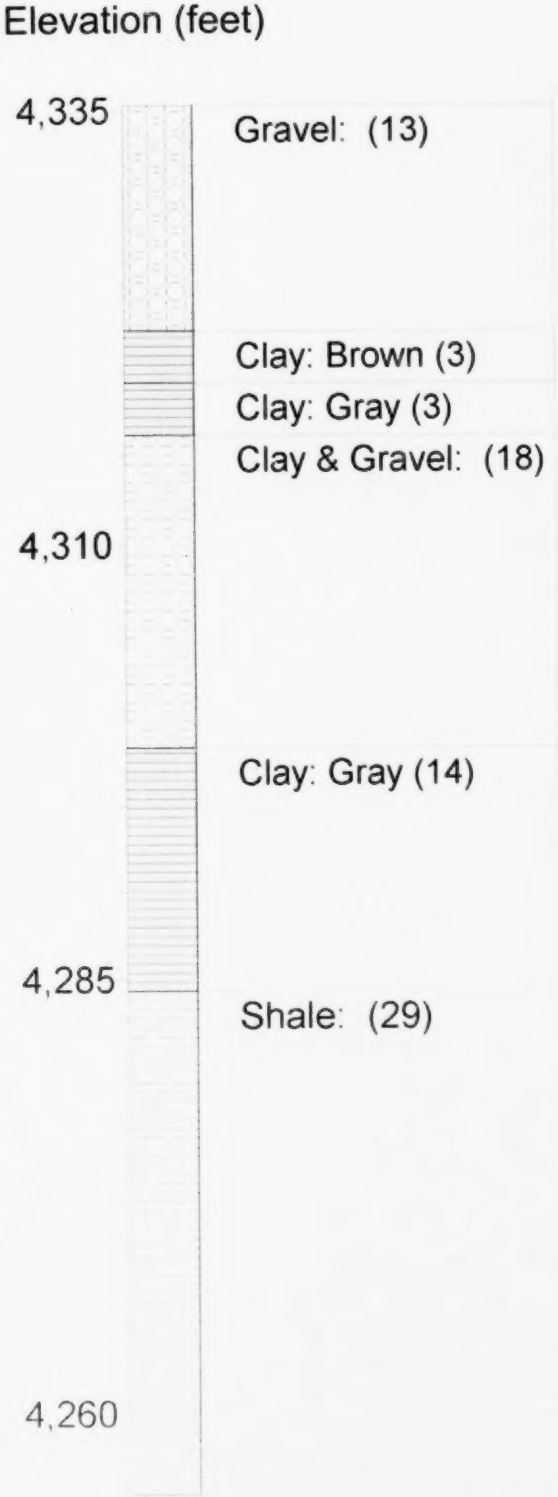
Location: SW-23-24-09W5
Elevation: 1289.2 m
Depth:201.2 m
Water Level elev.: 1287.5 m
Completion Interval: 195-201m
Driller: Alken Basin
Date: July 28, 2000
Monitoring Well #759

Test Hole 5

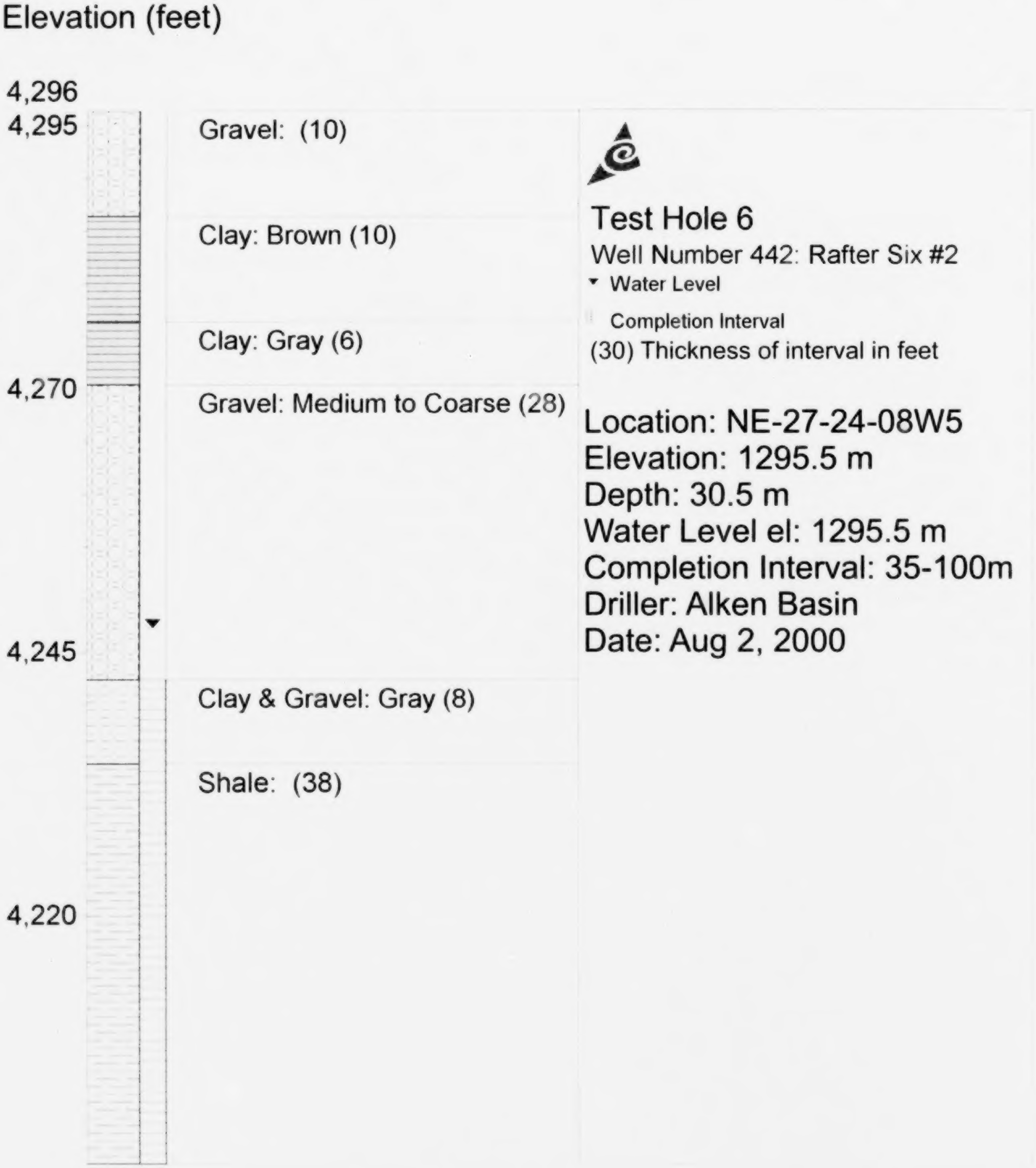
Well Number 444: Bow Valley South

- Water Level
- Completion Interval

(30) Thickness of interval in feet


Elevation (feet)
4,335
4,310
4,285
4,260
Gravel: (13)
Clay: Brown (3)
Clay: Gray (3)
Clay & Gravel: (18)
Clay: Gray (14)
Shale: (29)

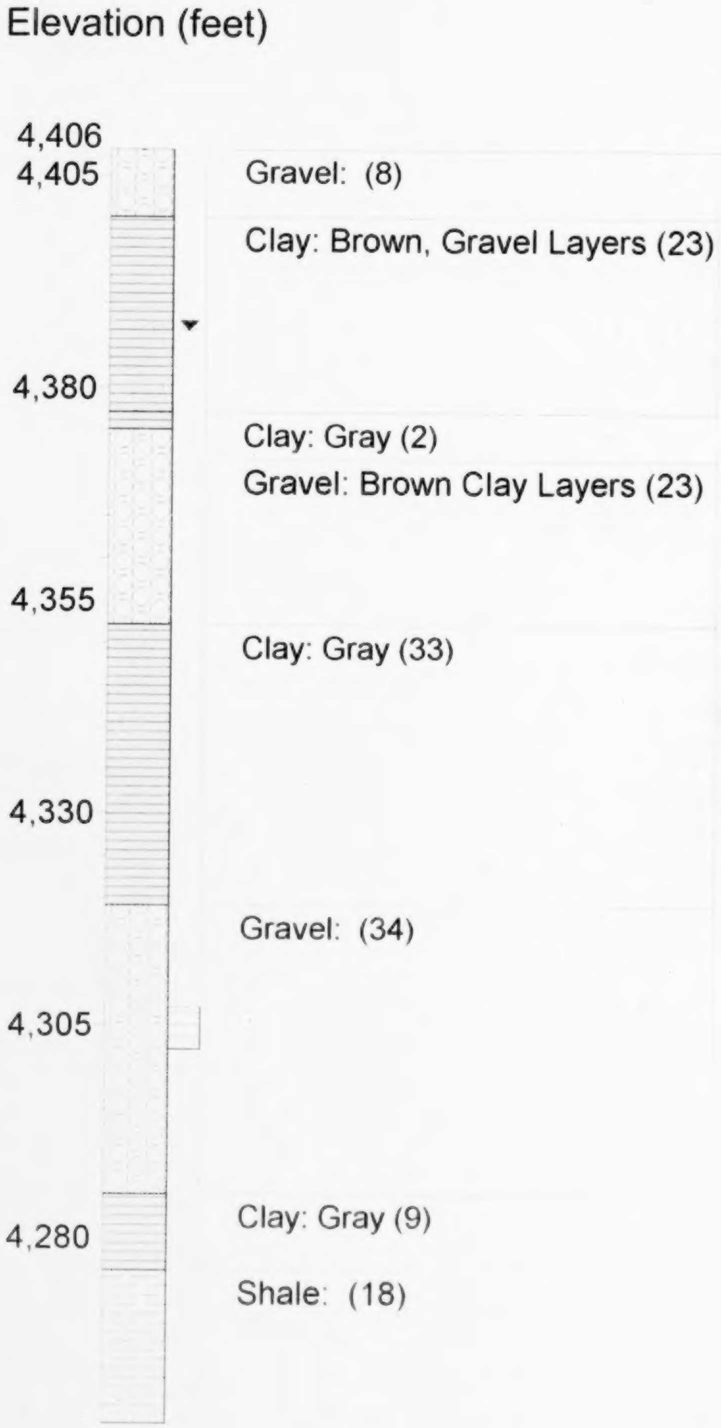
Location: 02-27-24-08W5
Elevation: 1321.3 m
Depth:24.4 m
Water Level elev.: dry
Completion Interval: none
Driller: Alken Basin
Date: August 1, 2000
Reclaimed


Elevation (feet)
4,296
4,295
4,270
4,245
4,220
Gravel: (10)
Clay: Brown (10)
Clay: Gray (6)
Gravel: Medium to Coarse (28)
Clay & Gravel: Gray (8)
Shale: (38)
▾ Water Level
Completion Interval
(30) Thickness of interval in feet

Test Hole 6

Well Number 442: Rafter Six #2

Location: NE-27-24-08W5
Elevation: 1295.5 m
Depth: 30.5 m
Water Level el: 1295.5 m
Completion Interval: 35-100m
Driller: Alken Basin
Date: Aug 2, 2000


Elevation (feet)
4,406
4,405
4,380
4,355
4,330
4,305
4,280
Gravel: (8)
Clay: Brown, Gravel Layers (23)
Clay: Gray (2)
Gravel: Brown Clay Layers (23)
Clay: Gray (33)
Gravel: (34)
Clay: Gray (9)
Shale: (18)

Test Hole 7

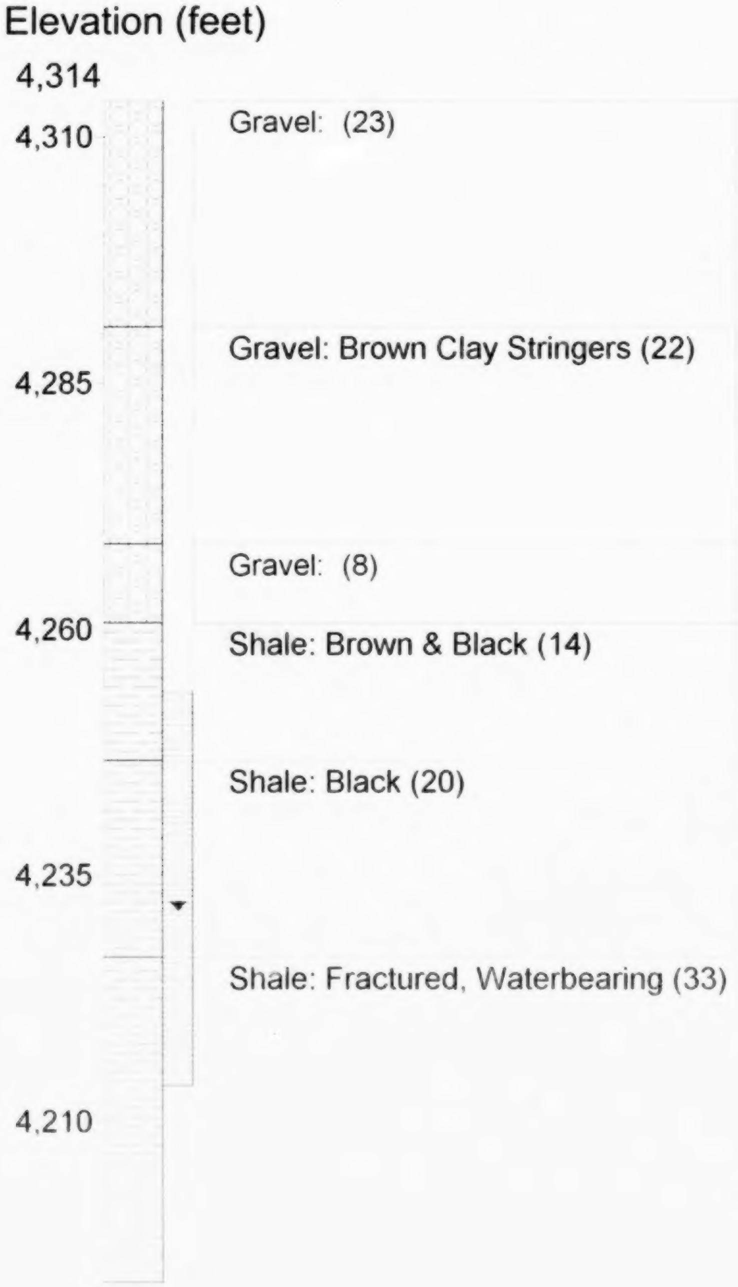
Well Number 487: Yamnuska

▾ Water Level

‖ Completion Interval

(30) Thickness of interval (feet)

Location:NW-08-25-08 W5
Elevation: 1342.7 m
Depth:45.72. m
Water Level el: 1337.3 m
Completion:30.8-32.3 m
Driller: Alken Basin
Date: Sept 20, 2000


Elevation (feet)
4,314
4,310
4,285
4,260
4,235
4,210
Gravel: (23)
Gravel: Brown Clay Stringers (22)
Gravel: (8)
Shale: Brown & Black (14)
Shale: Black (20)
Shale: Fractured, Waterbearing (33)

Test Hole 8

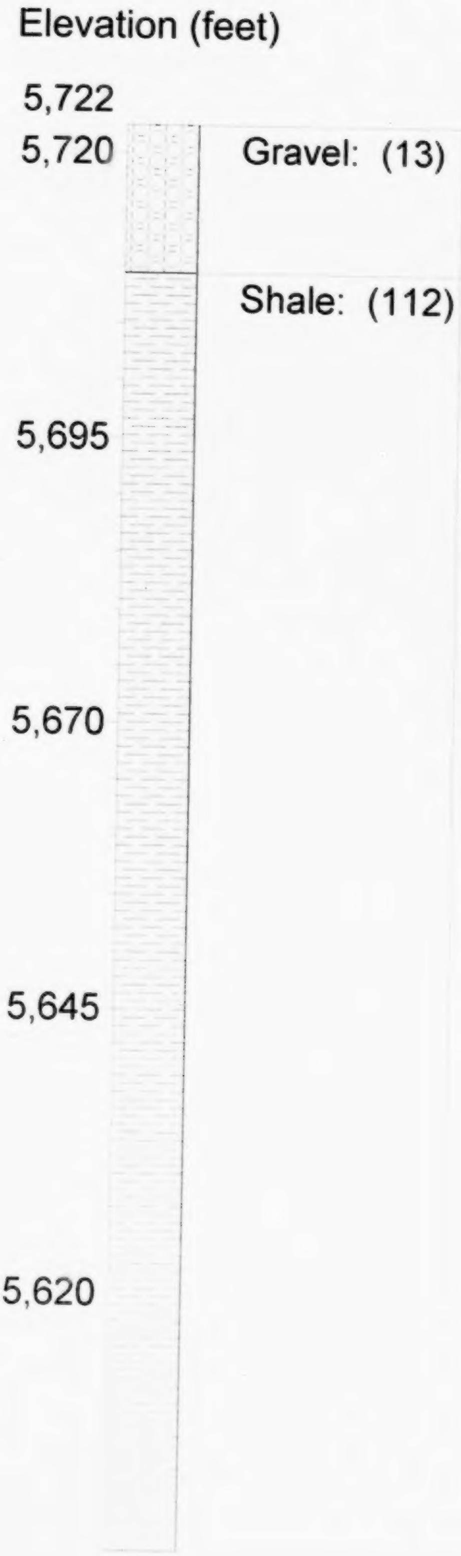
Well Number 490: Heart Creek

▾ Water Level

▯ Completion Interval

(30) Thickness of interval in feet

Location: NE-15-24-09W5
Elevation: 1314.75.3 m
Depth:36.6 m
Water Level el: 1290.4 m
Completion: 18.3-30.5 m
Driller: Alken Basin
Date: Oct 21,2000


Elevation (feet)
5,722
5,720
5,695
5,670
5,645
5,620
Gravel: (13)
Shale: (112)

Test Hole 9

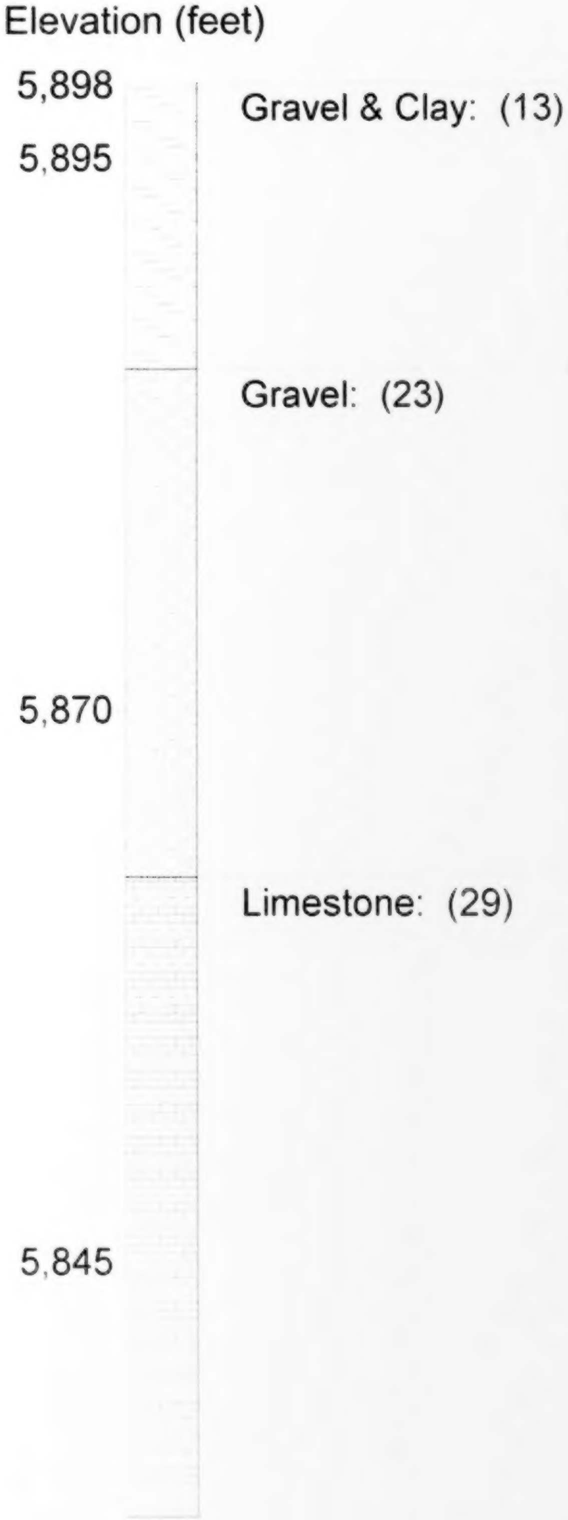
Well Number 491: Mt Shark

▪ Water Level

Completion Interval

(30) Thickness of interval in feet

Location: NW-07-22-10W5
Elevation: 1744.1 m
Depth:38.1 m
Water Level el: 1733.5 m
Completion: 5.8-38.1m
Driller: Alken Basin
Date: Sept 23, 2000


Elevation (feet)
5,898
5,895
5,870
5,845
Gravel & Clay: (13)
Gravel: (23)
Limestone: (29)

Test Hole 10

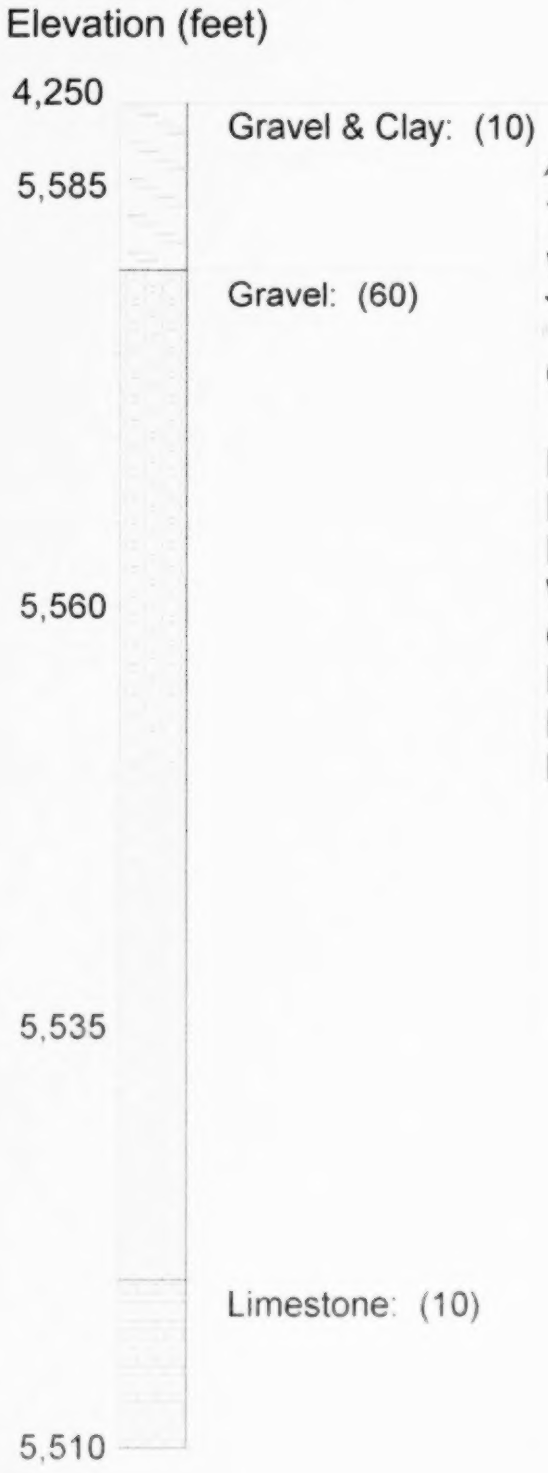
Well Number 493: Mt Buller

- Water Level

Completion Interval

(30) Thickness of interval (feet)

Location: SW-17-22-10W5
Elevation: 1797.8 m
Depth:19.8 m
Water Level elev.: dry
Completion Interval: dry
Driller: Alken Basin
Date: Sept 23, 2000
Reclaimed


Elevation (feet)
4,250
5,585
5,560
5,535
5,510
Gravel & Clay: (10)
Gravel: (60)
Limestone: (10)

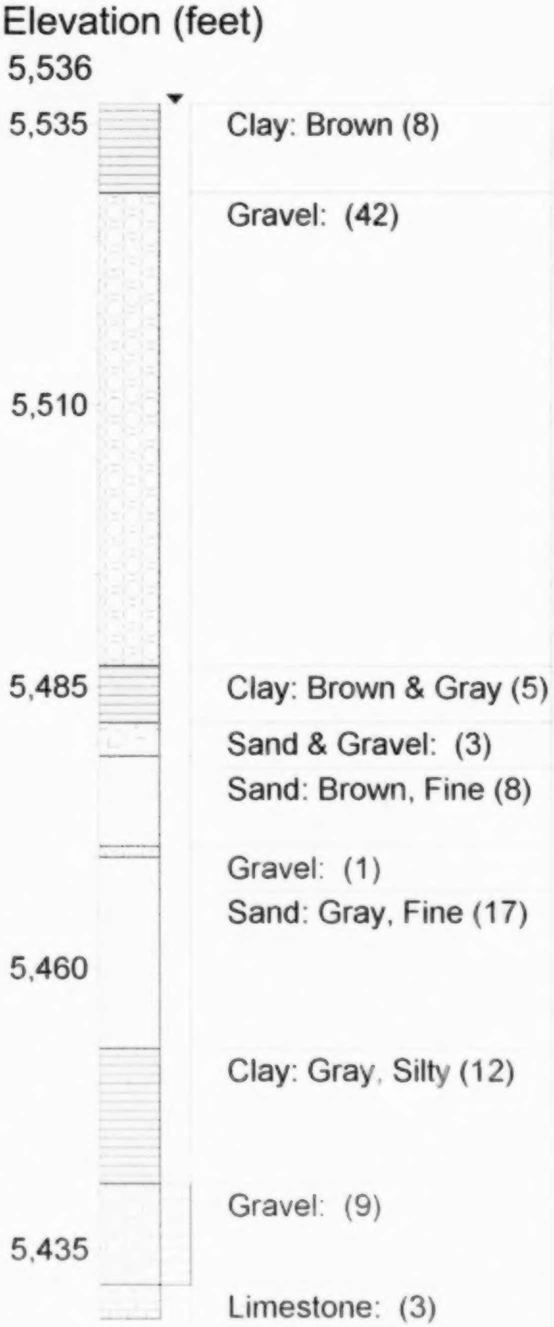
Test Hole 11

Well Number 496: Driftwood Day Use

- Water Level
- Completion Interval

(30) Thickness of interval (feet)

Location: SW-18-24-09W5
Elevation: 1703.7 m
Depth:24.4 m
Water Level elev: 1693 m
Completion Interval:17.7-21.3m
Driller: Alken Basin
Date: Sept 24, 2000
Monitoring Well #761


Elevation (feet)
5,536
5,535
5,510
5,485
5,460
5,435
Clay: Brown (8)
Gravel: (42)
Clay: Brown & Gray (5)
Sand & Gravel: (3)
Sand: Brown, Fine (8)
Gravel: (1)
Sand: Gray, Fine (17)
Clay: Gray, Silty (12)
Gravel: (9)
Limestone: (3)

Test Hole 12

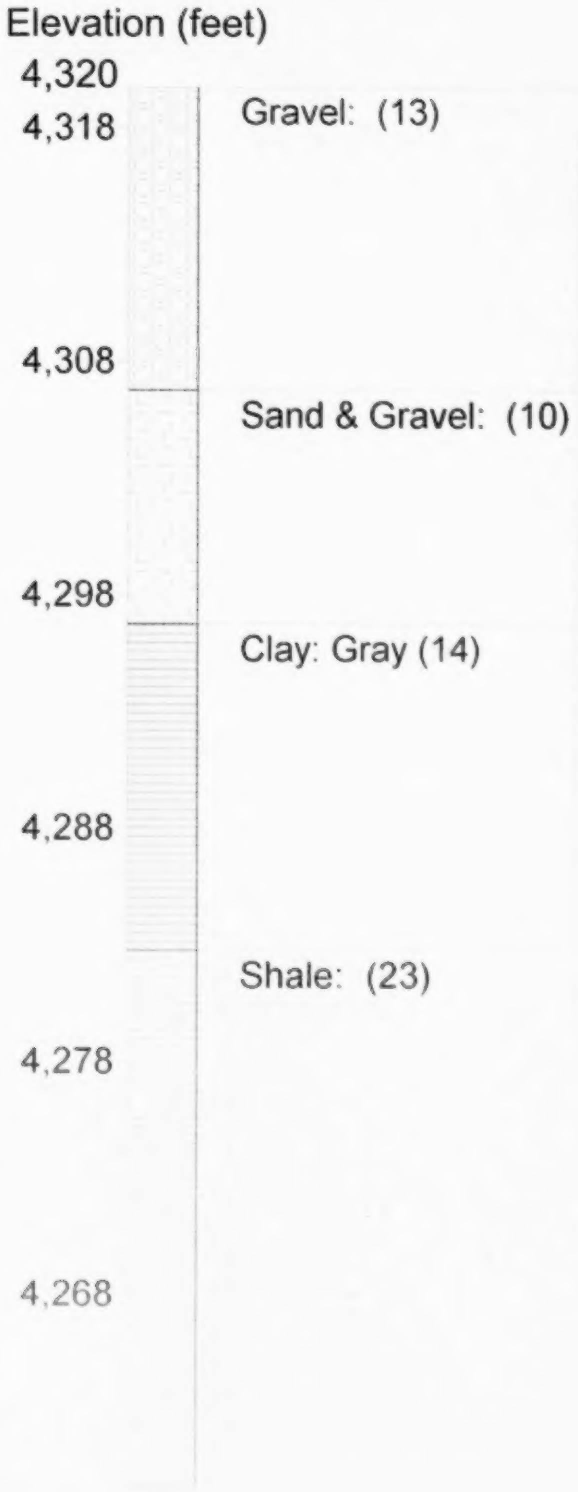
Well Number 497: Spray Ranger Station

▾ Water Level

▯ Completion Interval

(30) Thickness of interval (feet)

Location: SE-31-23-10W5
Elevation: 1687.5 m
Depth:32.9 m
Water Level elev.: 1685m
Completion Interval: 29.3-32.0 m
Driller: Alken Basin
Date: Sept 25, 2000
Monitoring Well #762

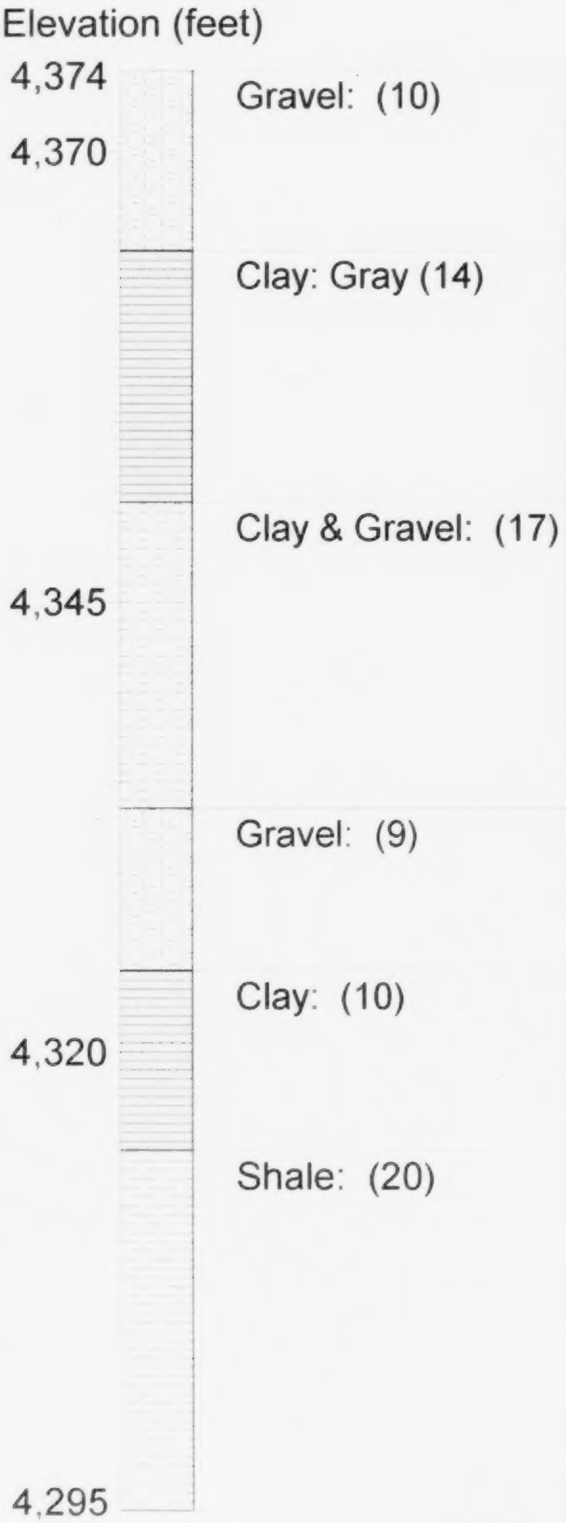

Elevation (feet)
4,320
4,318
4,308
4,298
4,288
4,278
4,268
Gravel: (13)
Sand & Gravel: (10)
Clay: Gray (14)
Shale: (23)

Test Hole 13

Well Number 489 Yamnuska #2

▾ Water Level
Completion Interval
(30) Thickness of interval (feet)

Location: NW-05-25-08W5
Elevation: 1316.6 m
Depth:18.3 m
Water Level elev: n/a
Completion Interval: n/a
Driller: Alken Basin
Date: Oct 2, 2000
Reclaimed


Elevation (feet)
4,374
4,370
4,345
4,320
4,295
Gravel: (10)
Clay: Gray (14)
Clay & Gravel: (17)
Gravel: (9)
Clay: (10)
Shale: (20)

Test Hole 14

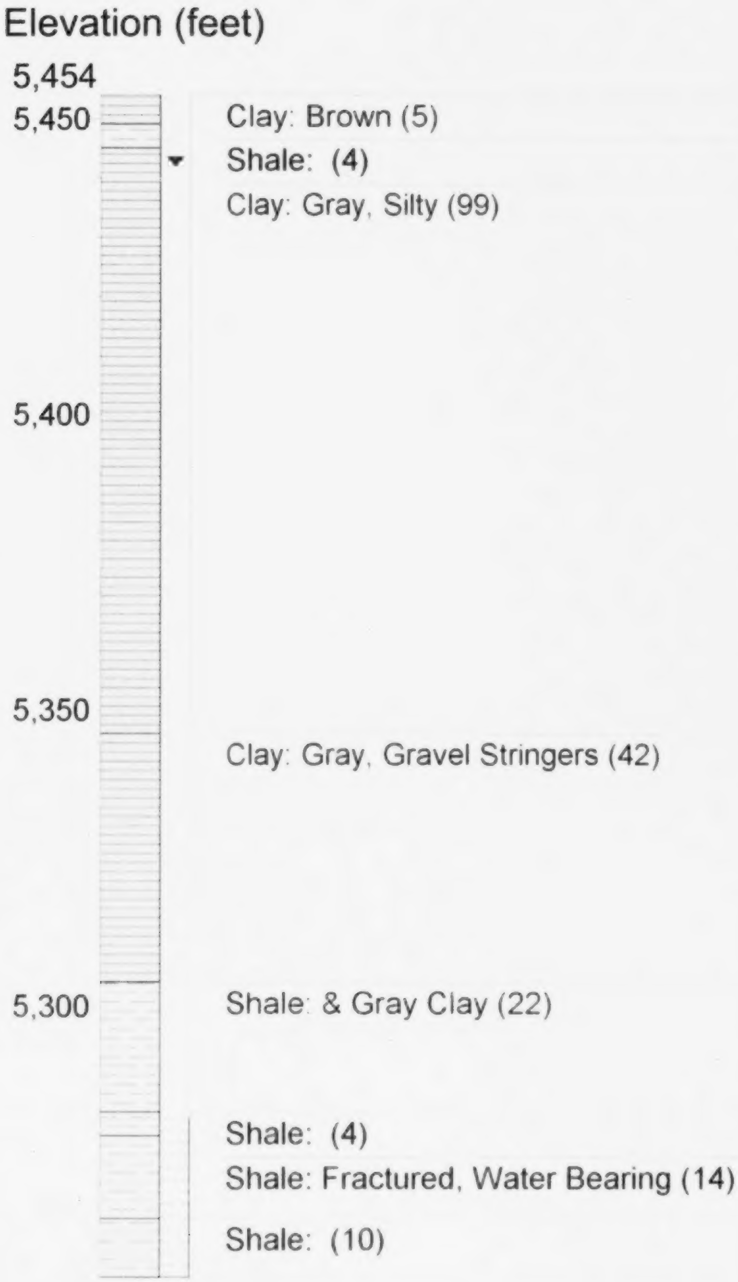
Well Number 488: Yamnuska #3

- Water Level

Completion Interval

(30) Thickness of interval in feet

Location: NE-08-25-08W5
Elevation: 1333.3 m
Depth:24.4 m
Water Level elev: n/a m
Completion Interval:n/a
Driller: Alken Basin
Date: Oct 3, 2000
Reclaimed
located near gravel pit
on south side of Hwy 1A
and east of Hwy 1X


Elevation (feet)
5,454
5,450
5,400
5,350
5,300
Clay: Brown (5)
Shale: (4)
Clay: Gray, Silty (99)
Clay: Gray, Gravel Stringers (42)
Shale: & Gray Clay (22)
Shale: (4)
Shale: Fractured, Water Bearing (14)
Shale: (10)

Test Hole 15

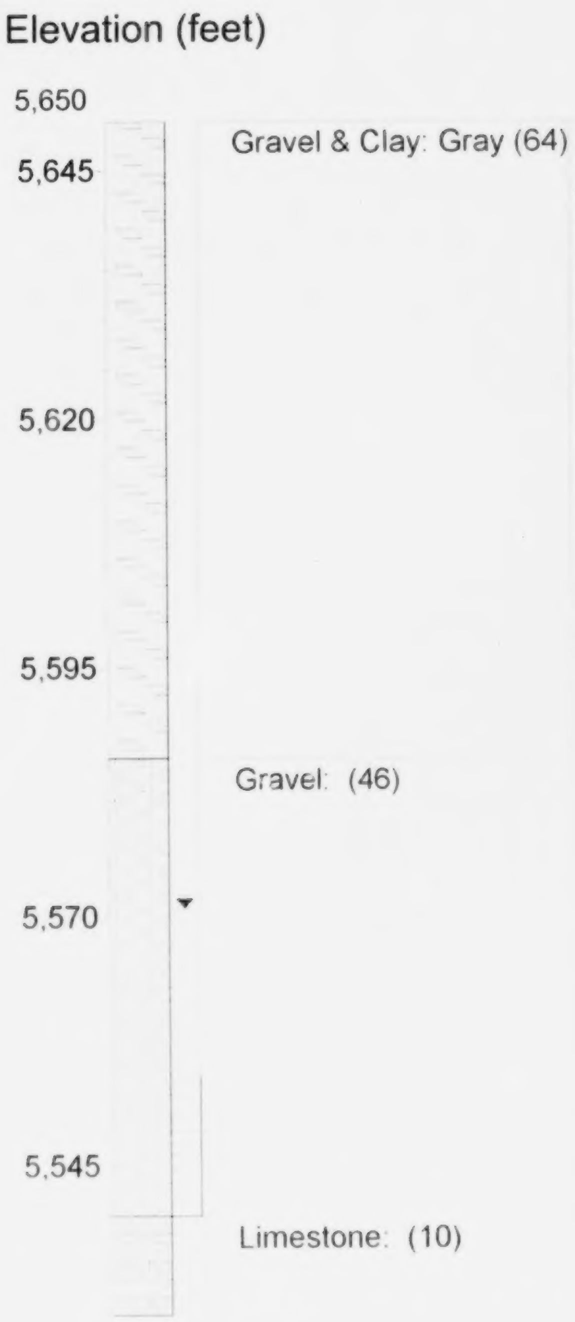
Well Number 498: Goat Creek

▾ Water Level

Completion Interval

(30) Thickness of interval in feet

Location:NW-24-24-11W5
Elevation: 1662.3 m
Depth:61.0 m
Water Level el: 1659.6 m
Completiol: 52.7-61.0 m
Driller: Alken Basin
Date: Oct 4, 2000
Monitoring Well #763


Elevation (feet)
5,650
5,645
5,620
5,595
5,570
5,545
Gravel & Clay: Gray (64)
Gravel: (46)
Limestone: (10)

Test Hole 16

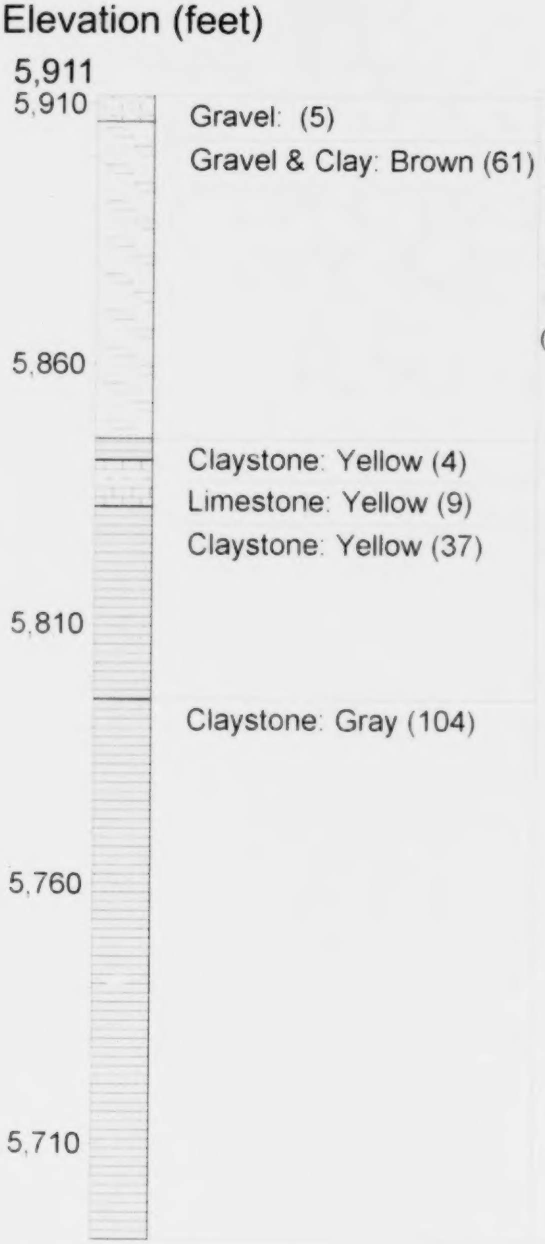
Well Number 495: Spray Lakes Day Use

▾ Water Level

Completion Interval

(30) Thickness of interval (feet)

Location: SW-03-23-10W5
Elevation: 1722.0 m
Depth:36.6 m
Water Level el: n/a
Completion Interval: 27.4-36.6 m
Driller: Alken Basin
Date: Oct 5, 2000


Elevation (feet)
5,911
5,910
5,860
5,810
5,760
5,710
Gravel: (5)
Gravel & Clay: Brown (61)
Claystone: Yellow (4)
Limestone: Yellow (9)
Claystone: Yellow (37)
Claystone: Gray (104)

Test Hole 17

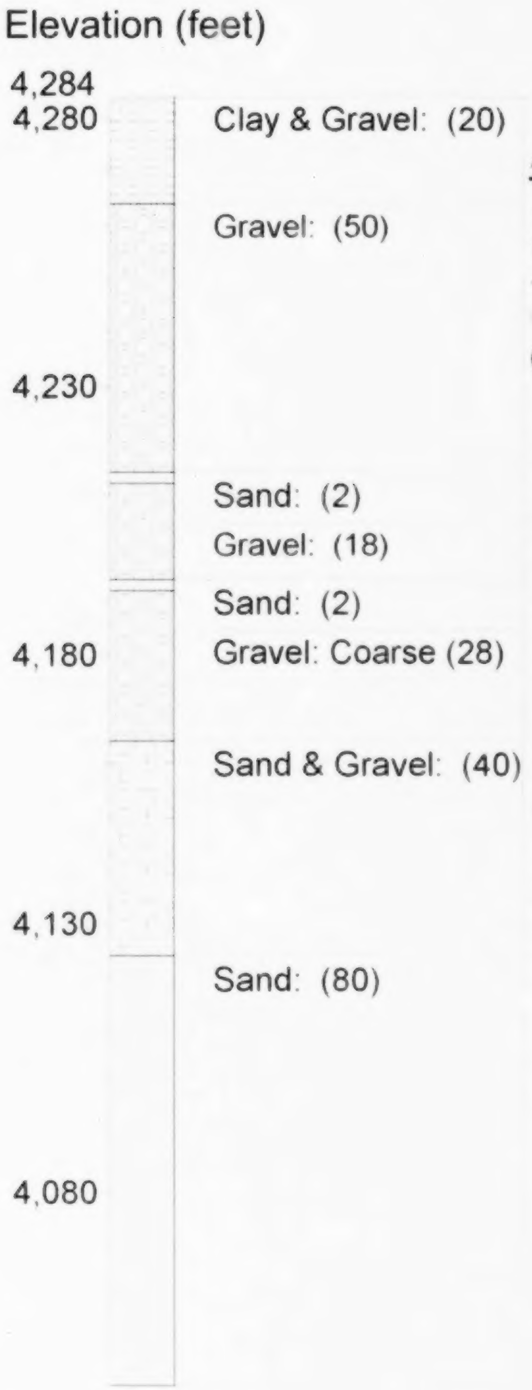
Well Number 494: Buller Day Use (East Lot)

▾ Water Level

Completion Interval

(30) Thickness of interval in feet

Location: SW-17-22-10W5
Elevation: 1801.8 m
Depth:67.1 m
Water Level elev: dry
Completion Interval: n/a
Driller: Alken Basin
Date: Oct 6, 2000
Reclaimed


Elevation (feet)
4,284
4,280
4,230
4,180
4,130
4,080
Clay & Gravel: (20)
Gravel: (50)
Sand: (2)
Gravel: (18)
Sand: (2)
Gravel: Coarse (28)
Sand & Gravel: (40)
Sand: (80)

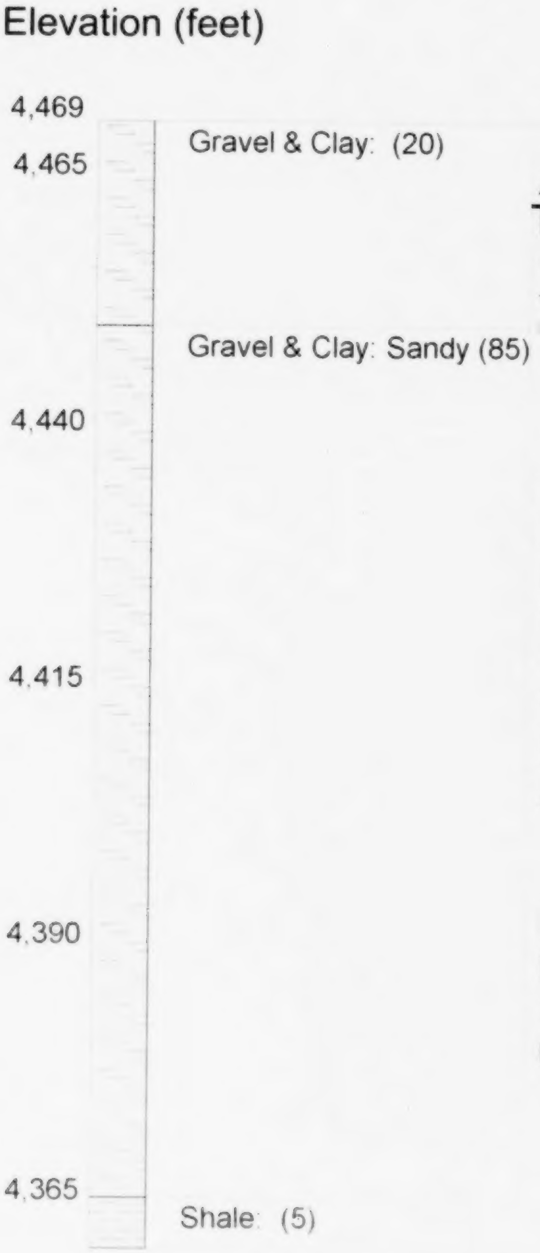
Test Hole 18

Well Number 628: Water Treatment Plant

▾ Water Level
Completion Interval
(30) Thickness of interval (feet)

Location: 11-28-24-10W5
Elevation: 1305.7 m
Depth:192.0 m
Water Level elev: n/a m
Completion Interval: n/a
Driller: Aaron Drilling Ltd
Date: Sept 4, 2001

EUB
Dept of Env Gap Lake
11-28-24-10W5
00/11-28-024-10W5


Elevation (feet)
4,469
4,465
4,440
4,415
4,390
4,365
Gravel & Clay: (20)
Gravel & Clay: Sandy (85)
Shale: (5)

Test Hole 19

Well Number 665: Yamanuska (Quarry Road)

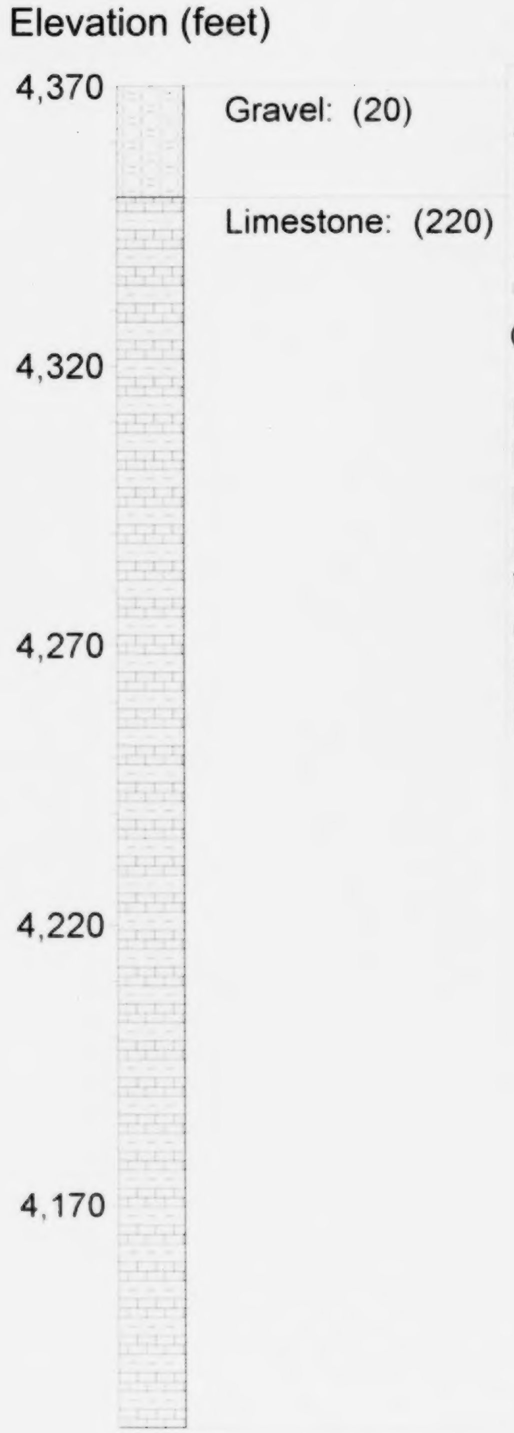
- Water Level

Completion Interval

(30) Thickness of interval in feet

Location: 12-08-25-08W5
Elevation: 1362.2 m
Depth:33.5 m
Water Level el: 1278 m
Completion Interval:n/a
Driller: Aaron Drilling Ltd.
Date: Oct 31,2001
Abandoned

EUB
Dept of Envt Gap Lake
12-8-25-8
00/12-08-25/08W5


Elevation (feet)
4,370
4,320
4,270
4,220
4,170
Gravel: (20)
Limestone: (220)

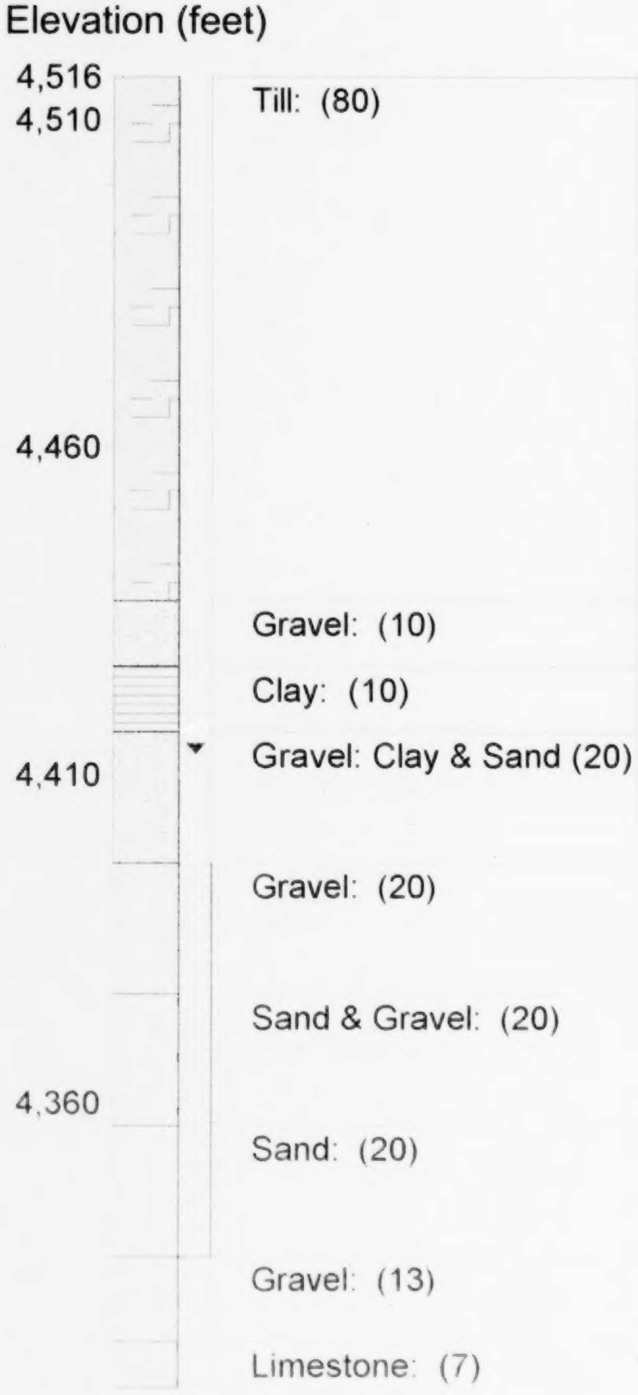
Test Hole 20

Well Number 629: Exshaw (Knowlerville)

- Water Level
▨ Completion Interval

(30) Thickness of interval (feet)

Location: 16-22-24-09W5
Plan 8610481 Block 2, Lot MR
Elevation: 1332.0 m
Depth: 73.2 m
Water Level el: 1302.4 m
Completion Interval: 7-73 m
Driller: Aaron Drilling Ltd
Date: Sept 2001


Elevation (feet)
4,516
4,510
4,460
4,410
4,360
Till: (80)
Gravel: (10)
Clay: (10)
Gravel: Clay & Sand (20)
Gravel: (20)
Sand & Gravel: (20)
Sand: (20)
Gravel: (13)
Limestone: (7)

Test Hole 21

Well Number 627: Harvie Heights

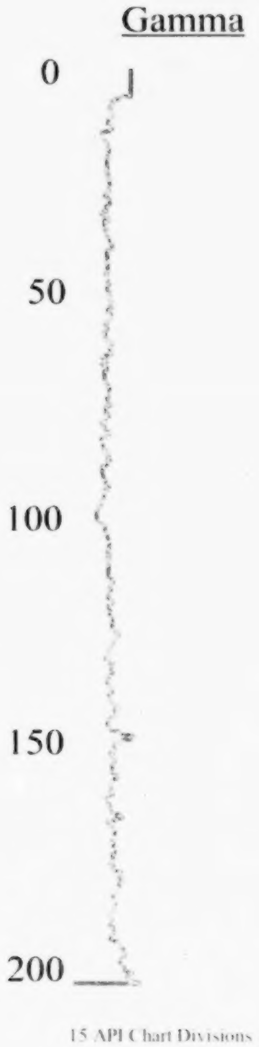
▾ Water Level

Completion Interval

(30) Thickness of interval (feet)

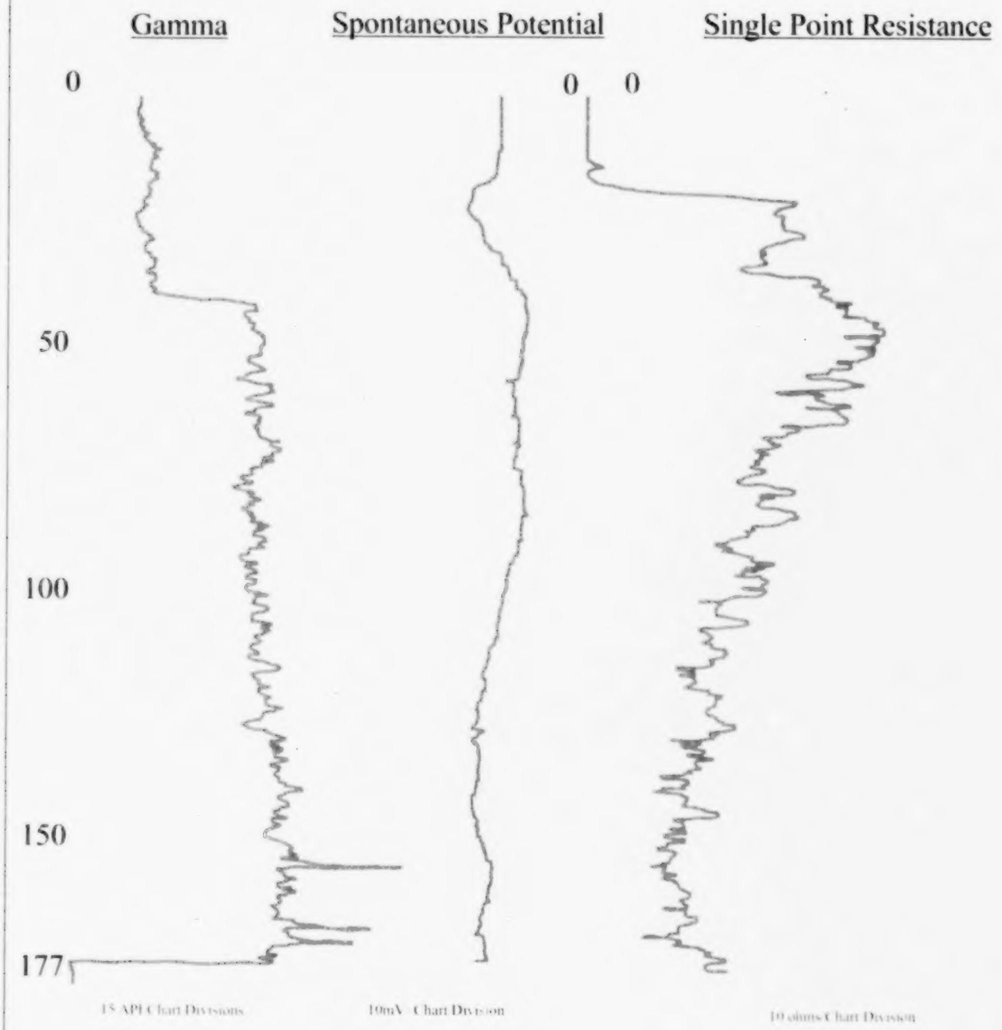
Location: SE-19-25-10W5
Block 6402HX, Block 6, Lot P6
Elevation: 1376.6 m
Depth:59.1 m
Water Level elev.: 1345 m
Completion Interval: 36.6-54.9 m
Driller: Aaron Drilling Ltd.
Date: Oct 2001
Monitoring Well #764

WEPA TH-2
Canmore Travel Booth
WEPA # 428
NW-5-25-10W5
Depth 280 ft.
Logged to 203 ft.



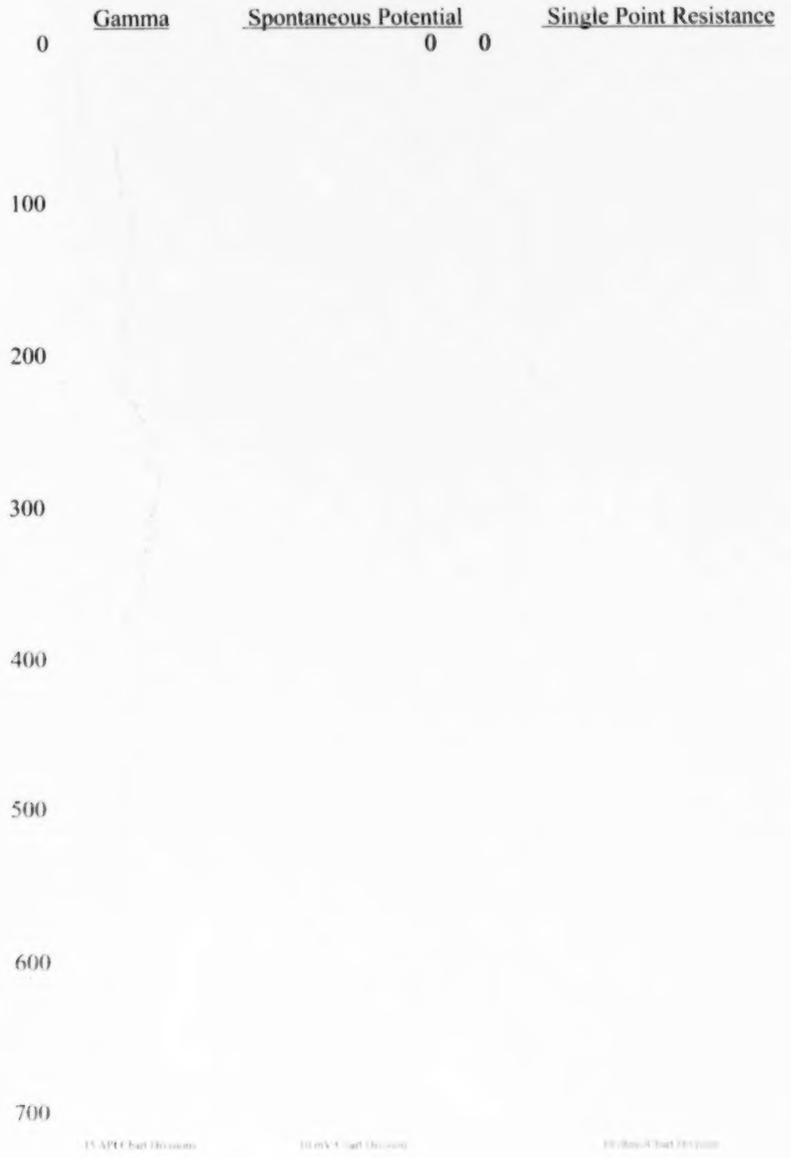
WEPA TH-3

Rafter Six Church
WEPA # 443
NE-27-24-8W5
Depth 220 ft.
Logged to 177 ft.



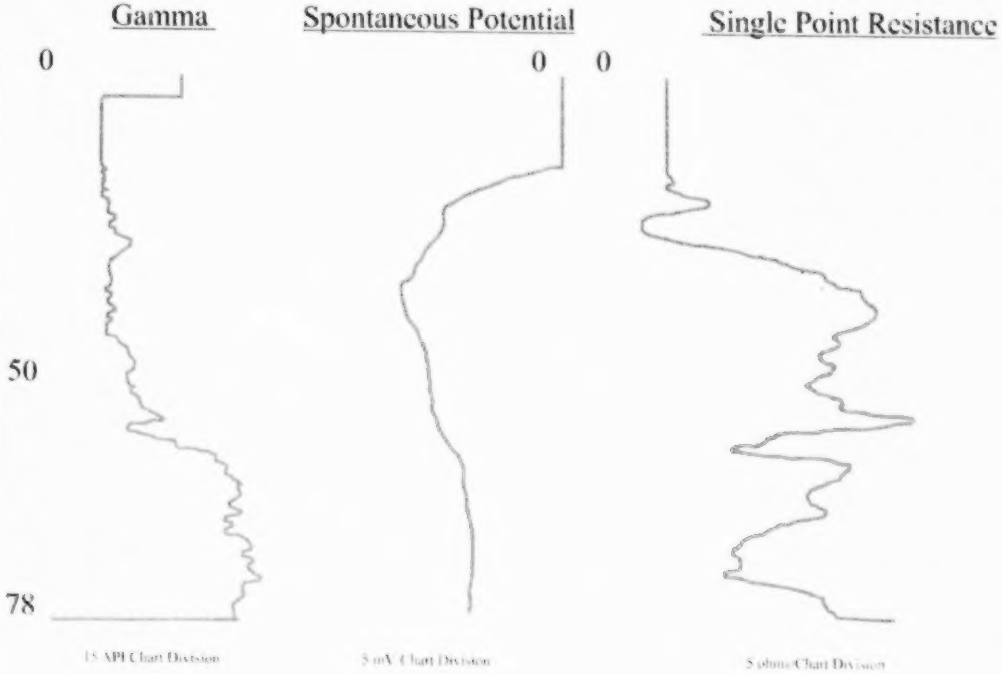
WEPA TH-4

Exshaw
WEPA # 427
NE-23-24-9W5
Depth 720 ft.



WEPA TH-5

Bow Valley South
WEPA # 444
2-27-24-8-W5
Depth 80 ft.



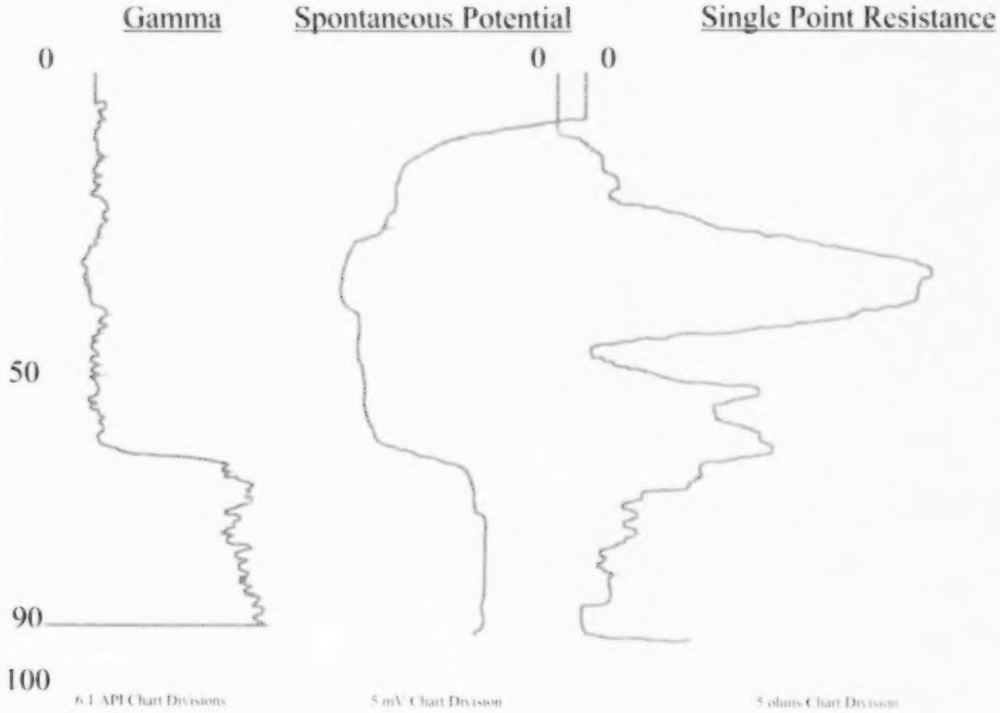
WEPA TH-6

Rafter Six #2

WEPA # 442

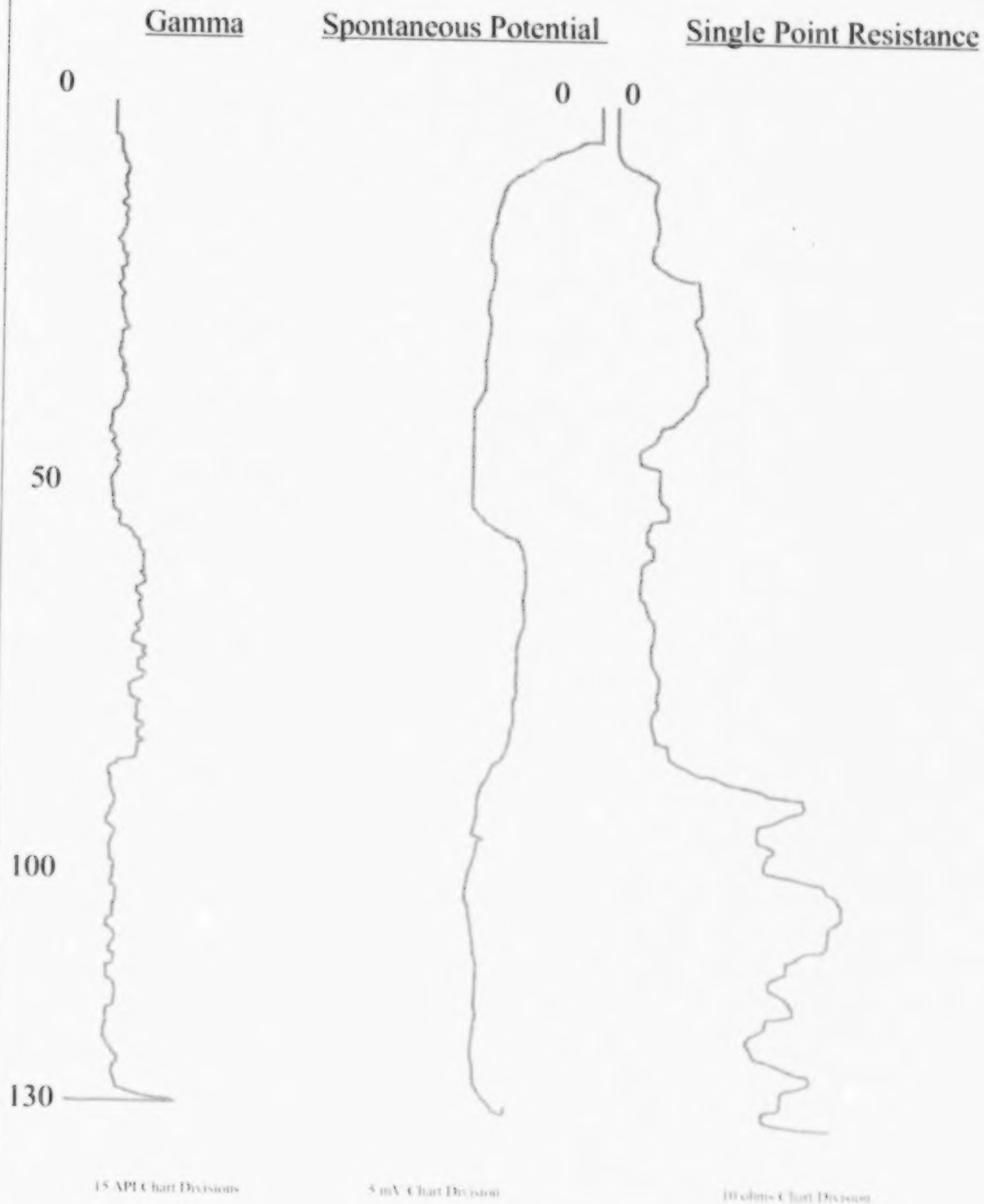
NE-27-24-8W5

Depth 100 ft.



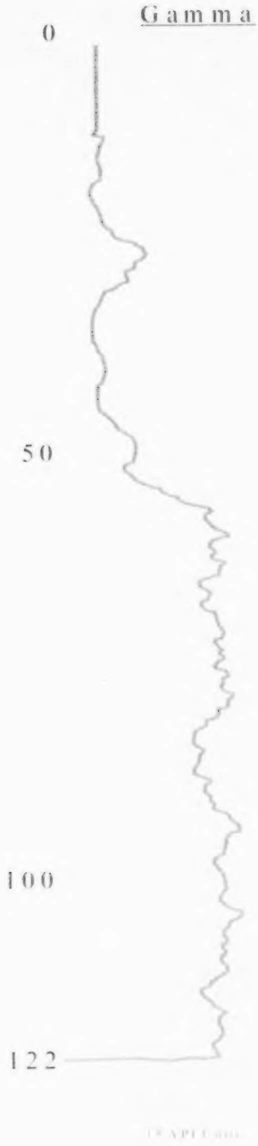
WEPA TH-7

Yamanuska Lot
WEPA # 487
NW-8-25-8W5
Depth 150 ft.
Logged to 130 ft.

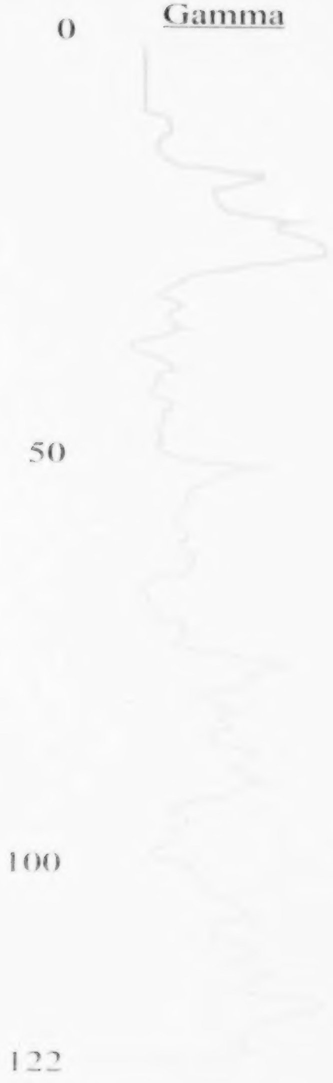


WEPA TH-8

Heart Creek
WEPA # 490
NE-15-24-9W5
Depth 120 ft.

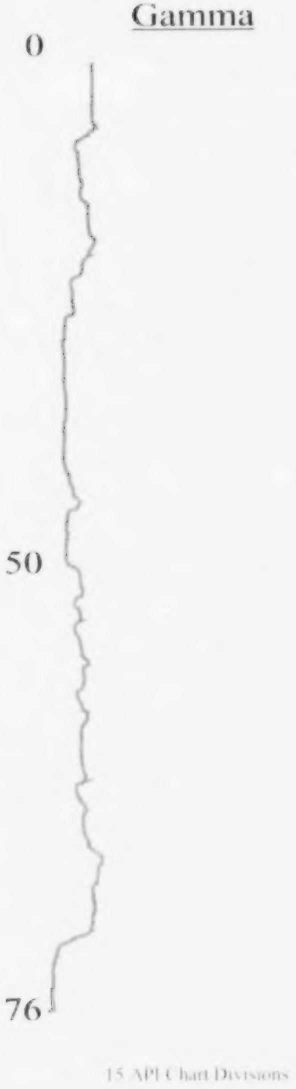


WEPA TH-9
Mt. Shark
WEPA # 491
NW-7-22-10W5
Depth 125ft.



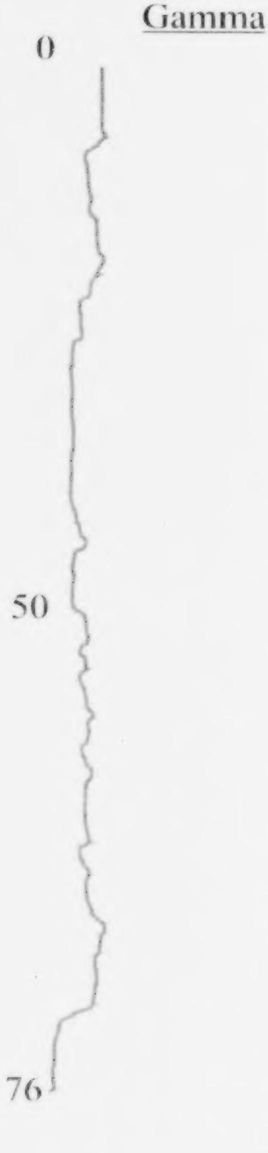
WEPA TH-11

Driftwood Day Use
WEPA # 496
SW-28-23-10W5
Depth 80 ft.



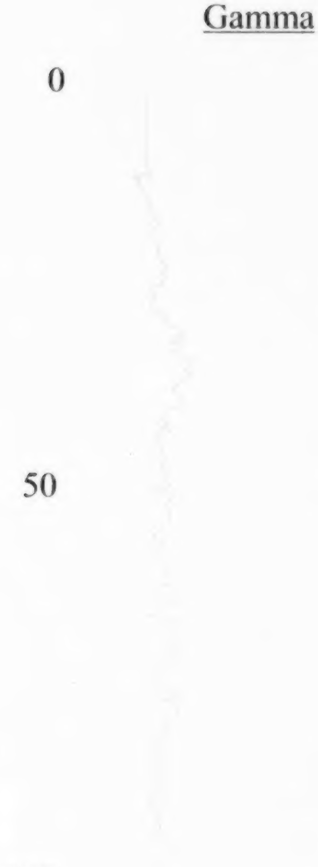
WEPA TH-12

Spray Lakes Ranger Station
WEPA 497
SE-31-23-10W5
Depth 108 ft.

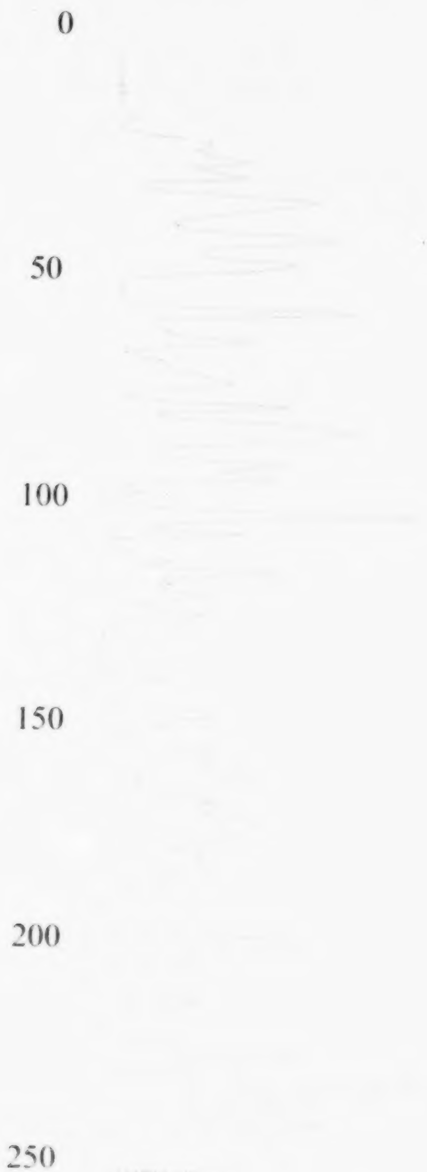


WEPA TH-19

Yamnuska
WEPA #665
12-8-25-8W5
Depth 110 ft.



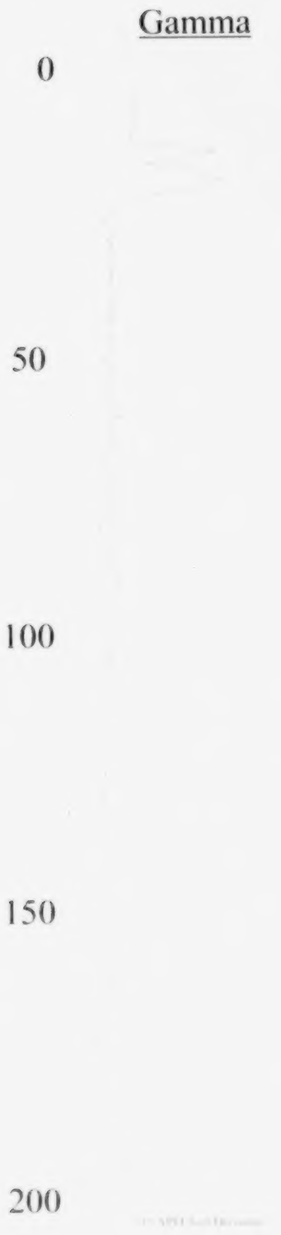
WEPA TH-20
Exshaw (Knowlerville)
WEPA # 629
16-22-24-9W5
Depth 240 ft.



Gamma

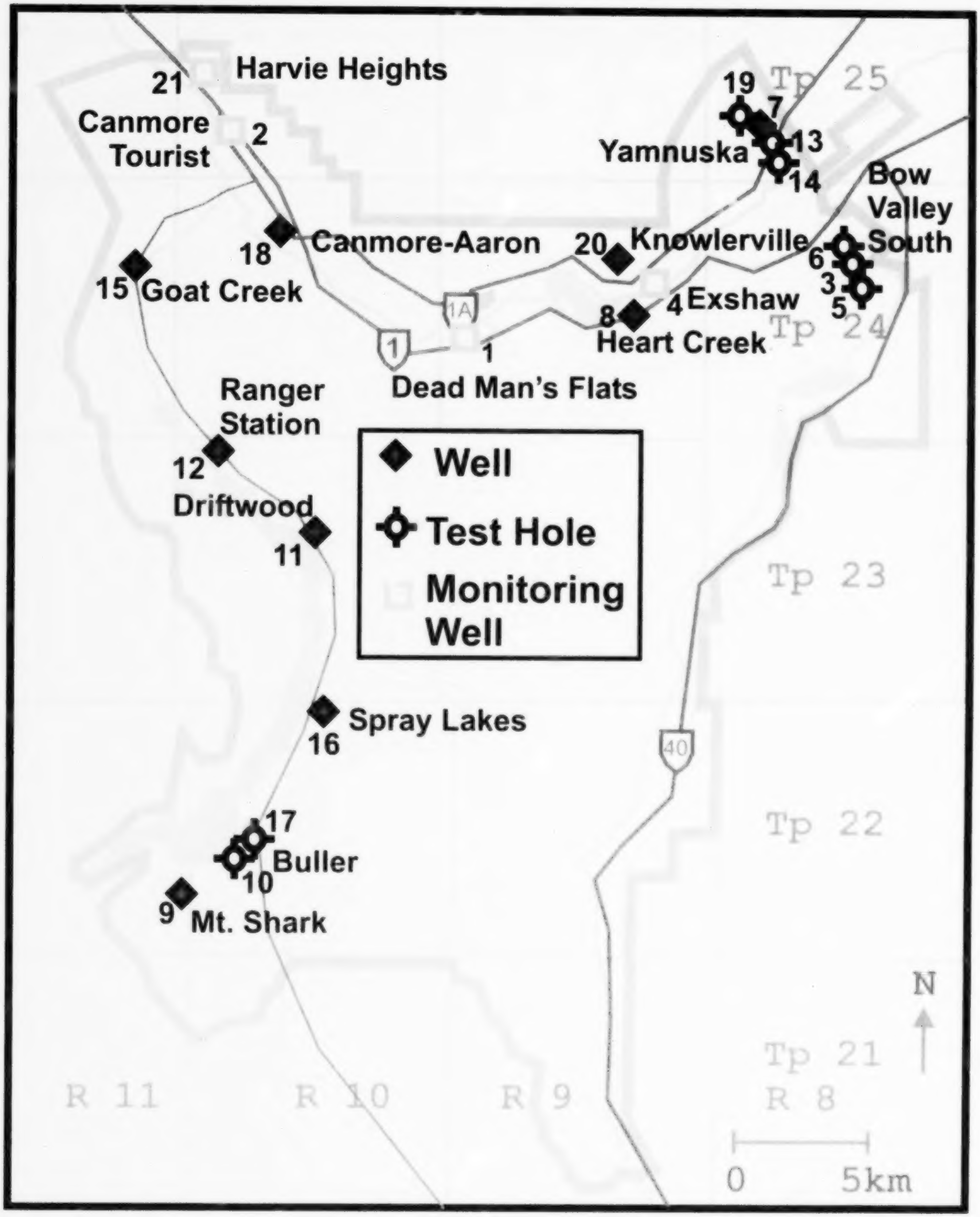
WEPA TH-21

Harvie Heights
WEPA # 627
SE-19-25-10W5
Depth 200 ft.



Gamma

Locations of Alberta Environment Exploration Holes, drilled under the Western Economic Partnership Agreement 1999-2001


21 Harvie Heights
Canmore Tourist 2
18 Canmore-Aaron
15 Goat Creek
19
7
Yamnuska
13
14
20 Knowlerville
Bow Valley South
6
3
5
4 Exshaw
8 Heart Creek
1A
1
1 Dead Man's Flats
Ranger Station
12
Driftwood
11
◆ Well
Test Hole
Monitoring Well
16 Spray Lakes
17
Buller
10
9 Mt. Shark
40
Tp 25
Tp 24
Tp 23
Tp 22
Tp 21
R 11
R 10
R 9
R 8
N
0
5km

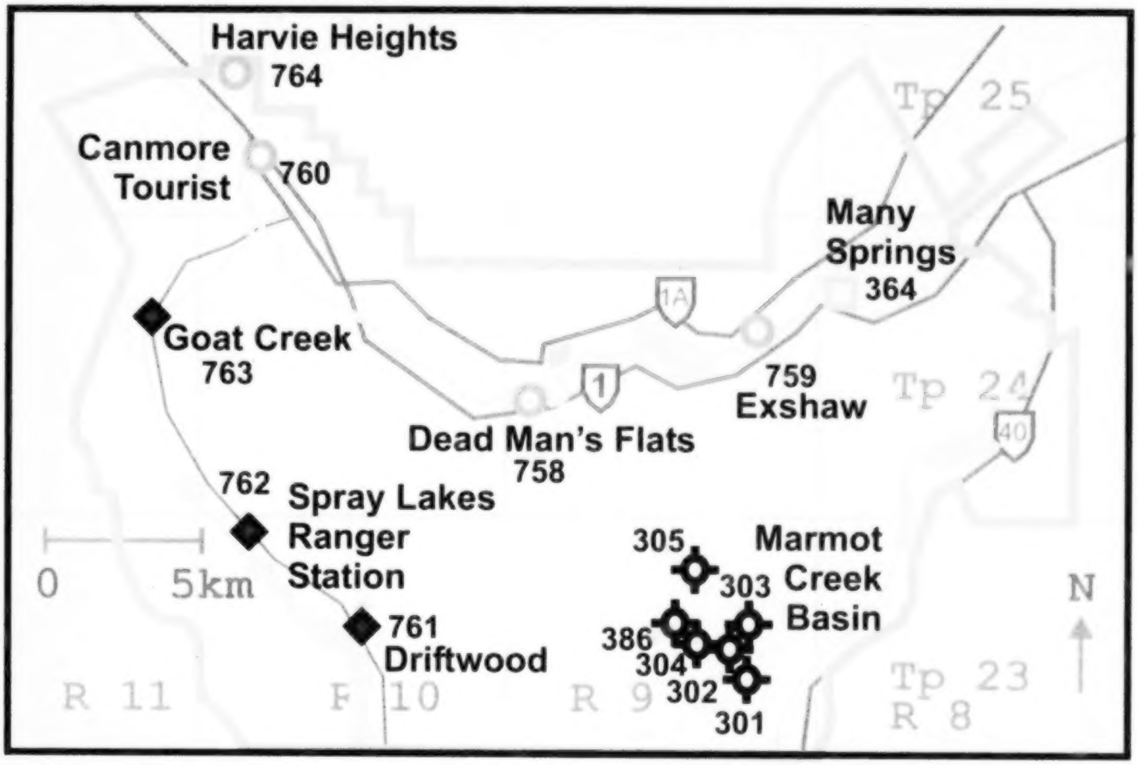
Appendix F

Alberta Environment Provincial Observation Wells

Observation Well Location Map
Table of Observation Wells

Alberta Environment
Provincial Observation Well Network

Canmore Corridor and
Northwestern Kananaskis Country


Harvie Heights
764
Canmore Tourist
760
Many Springs
364
Tp 25
1A
Goat Creek
763
1
759
Exshaw
Tp 24
40
Dead Man's Flats
758
762
Spray Lakes Ranger Station
0
5km
305
Marmot Creek Basin
303
386
304
302
301
761
Driftwood
N
Tp 23
R 11
R 10
R 9
R 8

Alberta Environment
Provincial Observation
Wells

□ Established
○ New
◆ New (spot readings)
⊕ Discontinued

Alberta Environment Provincial Observation Wells in the Canmore Corridor and Northwestern Kananaskis Country

ID no.	Name	Location	Record Start Date	Record End Date	Elevation (m)	Completion Depth (m)
301	Marmot Creek Basin S5250	14-11-23-9W5	11-Oct-1964	23-Jul-1997	1601.4	6.5-8.5
302	Marmot Creek Basin S5430	3-14-23-9W5	11-Oct-1964	1-Dec-1986	1642.0	8.04-9.14
303	Marmot Creek Basin N5475	6-15-23-9W5	9-Jul-1965	23-Jul-1997	1669.1	34.0-36.58
304	Marmot Creek Basin S6170	6-15-23-9W5	12-Jul-1965	22-Nov-1986	1870.0	12.0-14.33
305	Marmot Creek Basin N6770	11-22-23-9W5	14-Jul-1965	16-Jul-1996	2151.62	9.0-11.58
386	Marmot Creek Basin 2507E	6-15-23-9W5	30-Apr-1989	23-Jul-1997	1640.00	0-12.8
364	Many Springs	4-30-24-8W5	23-Jan-1987	current	1370	21.94-29.56
758	Dead Man's Flats	4-18-24-9W5	5-Nov-1999	current	1296.33	163.7-194.16
759	Exshaw	4-23-24-9W5	26-Oct-2000	current	1290.37	195.07-201.17
760	Canmore Tourist Info	13-5-25-10W5	3-May-2001	current	1315.35	59.44-62.48
761	Driftwood	4-28-23-10W5	5-Oct-2000	current	1704.5	17-68-21.34
762	Spray Lakes Ranger Station	1-31-23-10W5	5-Oct-2000	current	1688.29	29.26-32.00
763	Goat Creek	13-24-24-11W5	5-Oct-2000	current	1663.29	52.73-60.96
764	Harvie Heights	2-18-25-10W5	Jul 2002	current	1376.5	35.58-48.77

Updated charts of water levels are available from Monitoring Division, Alberta Environment, Oxbridge Place, 9820-105 Street, Edmonton, Alberta